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Developing Underwater Concrete Properties with and without Anti-washout Admixtures

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Abstract— This work represents an experimental investigation concerned with the development of concrete mixtures that can be used for underwater placing. These mixes shall satisfy certain requirements regarding flowability and viscosity (cohesiveness). The adopted design of the concrete mixtures discloses these main features: dispensing anti-washout admixtures, increasing the paste volume by means of pozzolana, limestone powder and bentonite powder. The work involves five groups with total number of twenty-three underwater-concrete mixes. First group uses anti-washout admixtures, the second group uses limestone powder, the third group uses bentonite powder and fourth& fifth group's uses limestone powder and bentonite powder. The concrete mixtures were tested for slump, slump flow, washout resistance (pH for water and Wight loss), segregation ratio, air content and compressive strength. Compressive strengths were evaluated at 7 and 28 days age for under-water casting as well as air casting conditions (276 cubes were tested). Test results indicated that the use of limestone powder and bentonite powder facilitates the production of flowable concrete mixtures with the added benefit of lower washout loss. The underwater concrete developed 28-day compressive strengths ranging from 20.4 to 52.2 N/mm^2.

Index Terms— Underwater concrete, limestone powder, bentonite powder, wight loss

1 INTRODUCTION

Placement of concrete underwater requires special considerations in selecting the mixture's constituents and proportions, which should be selected with consideration to the placing method [1].

The stability of fresh concrete is characterized by its resistance to washout loss, segregation ratio, and bleeding and is affected by the mixture proportioning, aggregate shape and gradation, extent of vibration consolidation, and placement conditions. When a mixture does not possess an adequate level of stability, the cement paste may not be cohesive enough to retain individual aggregate particles in a homogeneous suspension. This causes the different concrete constituents to separate, thus resulting in a significant reduction in mechanical properties and durability. In the case of under-water-cast concrete, differential velocity at the interface between freshly cast concrete and surrounding water can erode some of cementations materials and other fines. Such erosion can increase the turbidity and contamination of the surrounding water and impair strength and bond to rein-forcing steel and existing surfaces, as well as durability [2].

In recent years, limestone powder has been used in major underwater concrete construction projects. In these applications, the objective of using limestone powder is to improve the rheological behavior of concrete. Since limestone powder has a large surface area that absorbs the mixing water, it increases the cohesion and reduces bleeding of concrete [3]. The typical in situ residual compressive strength of concrete with adequate anti washout properties is generally greater than 0.70 [4].

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50% - 70% of self-consolidated UWC depends on turbulence of water and location of extracted cores for strength testing [5]. While a self-consolidating concrete intended for above-water applications can have a slump flow consistency of 625 to 675 mm, such value is typically limited to 450 to 550 mm under water to limit the risk of water dilution. Such dilution increases with free water resulting from the increase in consistency [6]. In the present work, it was aimed to produce underwater anti-washout concrete mixtures without the use of AWA. The performance criteria need to be justified in the fresh state are flowability and viscosity (cohesiveness).

2 EXPERIMENTAL PROGRAM

2.1 Materials

The materials of this experimental work were chosen from the local sources in Egypt. Ordinary Portland cement (CEM I 42.5N) was applied and the Egyptian standards 4756/1-2007 were considered in the production. Chemical and physical properties of used silica fume, limestone powder, bentonit powder and fly ash can be observed in Table1. Fine materials used in Figure 1, silica fume was locally produced in Egypt. It includes more than 96% amorphous silicon dioxide (SiO_2). It has specific gravity and bulk density 2.15 and 0.345 t/m^3 respectively. The classified fly ash used complies with the chemical and physical requirements as per BS 3892 Part 1, ASTM C618, and EN 450.Limestone powder Ataka in Suez City in Egypt was used in the experimental work. The chemical compositions of silica fume can be observed in Table1. The employed anti-washout admixtures (AWA) were of a powder-based welan gum specifically developed in order to be used with underwater concrete construction which can have benefits for the production of thixotropic mixtures with cohesive nature. The high-range water reducing (HRWR) of

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aqueous solution of modified poly-carboxylate basis was used to enhance workability and viscosity of the concrete mixtures. HRWR complies with ASTM-C-494 types G, and BS EN 934 part 2: 2001. It is worth mentioning that a clean tap drinking water was used in all mixtures. Fine aggregate used was locally available in natural siliceous sand with a fineness modulus of 2.36 and specific gravity of 2.63. The coarse aggregate are crushed dolomite with a maximum size of 10 mm and specific gravity 2.65 and absorption 2.05 respectively.

2.2 Mix Design

There were five groups with the total number of twenty-three underwater concrete mixes. First group uses anti-washout admixtures, the second group uses limestone powder, the third group uses bentonite powder and fourth& fifth group's uses mix between limestone powder and bentonite powder. The test program was designed and arranged to consider the effect of five different parameters as follows; group one anti-washout admixtures (0.0%, 0.2% , 0.3% , 0.4% and 0,5%) by weight of cement, group two limestone powder (0.0 % , 5.0% , 10% , 15 % and 20%) by weight of cement, group three bentonite powder (0.0% , 2.5% , 5% ,7.5% and 10%) , group four two types of fine materials (LSP and BNP) were used, the content of LSP changed from 7.5% to 2.5% by weight of cement, while BNP content changed from 2.5% to 7.5% according to the change of LSP content. Thus, the total content of both LSP plus BNP is always 10% and group five two types of fine materials (LSP and BNP) were used, the content of LSP changed from 15% to 0% by weight of cement, while BNP content changed from 0 to 15% according to the change of LSP content. Thus, the total content of both LSP plus BNP is always 15%. For all mixtures, a 450 kg/m^3 and 500 kg/m^3 cement content was used, and the pozzolanic materials were used as an addition to keep the cement content at an appropriate level. The silica fume content and fly ash (10% and 10%) respectively of cement weight for group one to group four. All concrete mixture has a w/b ratio of 0.35 and HRWR 3 % of cementitious materials weight. The adopted gravel to sand ratio was chosen based on preliminary tests of blending both of them with different ratios at saturated-surface dry condition to detect the ratio that provides minimum voids and consequently maximum unit weight. Based on the test results, the adopted crashed stone to sand ratio are R1=1.5:1 and R2=1:1 the ingredients of the investigated mixtures are shown in Table 2.

2.3 Casting and Curing

Underwater casting and air casting of concrete samples was carried out by using twelve 150 mm cubes which were casted from each mix (276 cubes for all mixes) to evaluate the compressive strength of both underwater casting and air casting conditions. The 150 mm cubic moulds were replicated underwater to the depth of 500 mm and the concrete was then poured from the top surface. The cubes were removed from the water tank. The cubes which cast in air and cast in water were left and covered for approximately 24 h, then remolded and cured in water at 20 + 3°C. All of the specimens for the Compressive strength tests were casted in moulds without being mechanically consolidated. The cubes were tested for compressive strength at 7 and 28 days. The compressive strength test results for concrete casted under water were compared with that casted normally (in air).

2.4 Mixing and Test Methods

All batches were mixed according to the same procedure in an open pan mixer. The mixing sequence consisted of placing the wet coarse aggregate and fine aggregate in the mixer and mixing for 30 s., the cement was then added and mixed for few seconds to obtain a homogeneous mix. The AWA powder was distributed into the mix followed by addition of water and HRWR. Once all mixture constituents were added, the concrete was mixed for 3 min. following a 1 min rest, the mixing was resumed for two additional minutes. The consistency and workability of the concrete mixes was evaluated using the slump test, whereas the viscosity was evaluated through the slump flow test. Because of its ease of operation and portability, the slump flow test is the most widely used method for evaluating concrete consistency in the laboratory and at construction sites. In this test, the diameter of the underwater concrete of the slump cone is a measure of flow, thus determining the consistency and cohesiveness of the concrete. The slump flow test was performed approximately 1 min after mixing. Figure 2, the concrete mixture's resistance to mass loss during under-water placement is measured by the US Army Crops of Engineers Method CRD-C61 [7]. The test consists of placing freshly mixed concrete into a steel perforated basket, which is then dropped through a column of water approximately 1.7 m deep. The basket is raised to the surface and the cycle is repeated two more times. The mass of the basket is measured at the beginning of and after the dunking cycles, so that the cumulative mass loss in percent can be determined. Using this method, a concrete mixture's resistance to mass loss during underwater placement can be measured and characterized. The sieve segregation test has primarily been developed to assess the resistance of self-compacting concrete to segregation [8].

Fig. 1. Fine materials used

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TABLE 1
CHEMICAL AND PHYSICAL PROPERTIES OF USED SILICA FUME, LIMESTONE POWDER , BENTONIT POWDER AND FLY ASH

Chemical properties	Silica fume	Limestone powder	Bentonit powder	Fly ash
SiO_2	96.00	6.49	54.27	47
Fe_2O_3	1.45	0.36	6.42	3.0
Al_2O_3	1.10	0.76	23.39	25
CaO	1.20	34.95	2.36	4.0
MgO	0.18	14.44	2.54	1.0
K_2O	1.20	0.10	0.42	0.5
Na_2O	0.45	0.67	1.02	0.2
SO_3	0.25	0.67	-	0.1
H_2O	0.85	-	-	-
Physical properties				
Color	Light gray	Yellow	Yellow	Grey
Specific gravity	2.15	2.71	2.22	2.2
Bulk density (kg/m^3)	345	1418	1022	-
Particle size (μm)	7.00	36	21	-

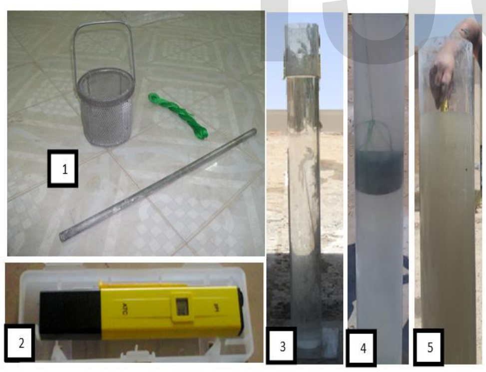

Fig. 2. Apparatus of washout resistance (Weight loss and pH water) and testing
1- Rod, Rope and Receiving Container 2- Apparatus of pH water 3- Washout tube 200 mm diameter 4- Test of weight loss 5- Test of pH

TABLE 2
CONCRETE MIXES PROPORTIONS

Group	Mix	W/b (%)	C (kg)	HRWR %	F to C	S.F (%)	FA (%)	AWA (%)	LSP (%)	BN (%)
Con.	MC	0.35	450	3	R1	10	10	0	-	-
	M1	0.35	450	3	R1	10	10	0.2	-	-
	M2	0.35	450	3	R1	10	10	0.3	-	-
G1	M3	0.35	450	3	R1	10	10	0.4	-	-
	M4	0.35	450	3	R1	10	10	0.5	-	-
	M5	0.35	450	3	R1	10	10	-	5	-
G2	M6	0.35	450	3	R1	10	10	-	10	-
	M7	0.35	450	3	R1			-	15	-
	M8	0.35	450	3	R1	10	10	-	20	-
	M9	0.35	450	3	R1	10	10	-	-	2.5
	M10	0.35	450	3	R1	10	10	-	-	5
G3	M11	0.35	450	3	R1	10	10	-	-	7.5
	M12	0.35	450	3	R1	10	10	-	-	10
	M13	0.35	450	3	R1	10	10	-	7.5	2.5
G4	M14	0.35	450	3	R1	10	10	-	5	5
	M15	0.35	450	3	R1	10	10	-	2.5	7.5
	M16	0.353	500	3	R2	15	-	-	15	0
	M17	0.353	500	3	R2	15	-	-	12.5	2.5
	M18	0.353	500	3	R2	15	-	-	10	5
G5	M19	0.353	500	3	R2	15	-	-	7.5	7.5
	M20	0.353	500	3	R2	15	-	-	5	10
	M21	0.353	500	3	R2	15	-	-	2.5	12.5
	M22	0.353	500	3	R2	15	-	-	0	15

Where
W/b: water/binder ratio C: cement content HRWR: high-range water reducing
R1=1.5:1 R2=1:1 FA: fly as S.F: silica fume AWA: anti-washout admixtures
LSP: Limestone powder BN: Bentonite powder

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3 TEST RESULTS AND DISCUSSION

3.1 Fresh Properties

In the fresh state, the tests are slump, slump flow, washout resistance (pH and weight loss) and segregation ratio. The measured fresh properties of all mixes are summarized in Table 3.

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TABLE 3

FRESH PROPERTIES OF (UWC)

Mix		Slump	Slump flow	pH water	Weight loss	Segregation	Air content
		(mm)	(mm)	-	(%)	(%)	(%)
Con.	M.C.	290	900	10.9	28	33	2.6
G1	M1	270	700	9.4	9	13	2.9
	M2	260	500	8.8	5	9	3.1
	M3	240	400	7.9	1	2.5	3.5
	M4	220	350	7.8	0	0	4
G2	M5	290	900	10.8	27	35	2.4
	M6	290	850	10.5	24	18	2.3
	M7	280	800	10	18	15	2
	M8	275	800	9.8	13	12	1.9
G3	M9	270	700	9.8	15	10	-
	M10	260	570	9.6	8	5	-
	M11	230	450	8.5	5	2	-
	M12	200	350	8	2.1	0.5	-
G4	M13	280	700	9.6	12	8	-
	M14	270	650	8.8	5	3	-
	M15	280	580	8.5	3	0.5	-
G5	M16	290	850	10.7	13	20	-
	M17	285	800	10.4	10	16.5	-
	M18	270	700	9.2	7	11	-
	M19	260	550	9	5	9.5	-
	M20	250	470	8.5	1	7	-
	M21	230	380	7.9	0	4	-
	M22	210	300	7.6	0	2.6	-

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3.1.1 Slump and Slump Fow

Results of the investigations on fresh concrete properties of all mixes are illustrated in Table 3. The slump flow of all mixes was in the range of 300 – 950 mm. Figure 3G1 and 4-G1 shows slump flow for the different mixes just after mixing. It can be noted that the slump flow decreased as AWA dosage increased which also agrees with the results given in [9-11]. This is attributed to AWA, which increases the viscosity and the water retention of concrete mix. For example, as a result of changing AWA from 0.0% to 0.5% by weight of cement, the slump flow changed from 900 to 350 mm respectively. The effect of limestone powder on slump flow showed that the slump flow slightly decreased as limestone powder increased. For instance, as it can be observed in Figure 3G2 and 5G2 regarding concrete mixes group two, due to the changes of limestone powder from 0.0% to 20% by weight of cement, the slump flow changed from 900mm to 800 mm respectively. On the other hand, the slump flow decreased as bentonite powder increased. For example, as it can be observed in Figure 3G3 and 4G3 regarding concrete mixes group three, due to the changes of bentonite powder from 0.0% to 10% by weight of cement, the slump flow changed from 900 mm to 350 mm respectively. Figure 3 and 4G5, in the mixes prepared with LSP and BNP as fine materials, the contents of LSP changed from 15 to 0% by weight of cement, while BNP content was changed from 0.0 to 15% according to the change of LSP content. Thus, the total content of both LSP plus BNP is always 15% by weight of cement. Test results indicated that the use of 10% of LSP (5% BNP) gave very good results of fresh and hardened concrete properties the recorded slump flow 700 mm.

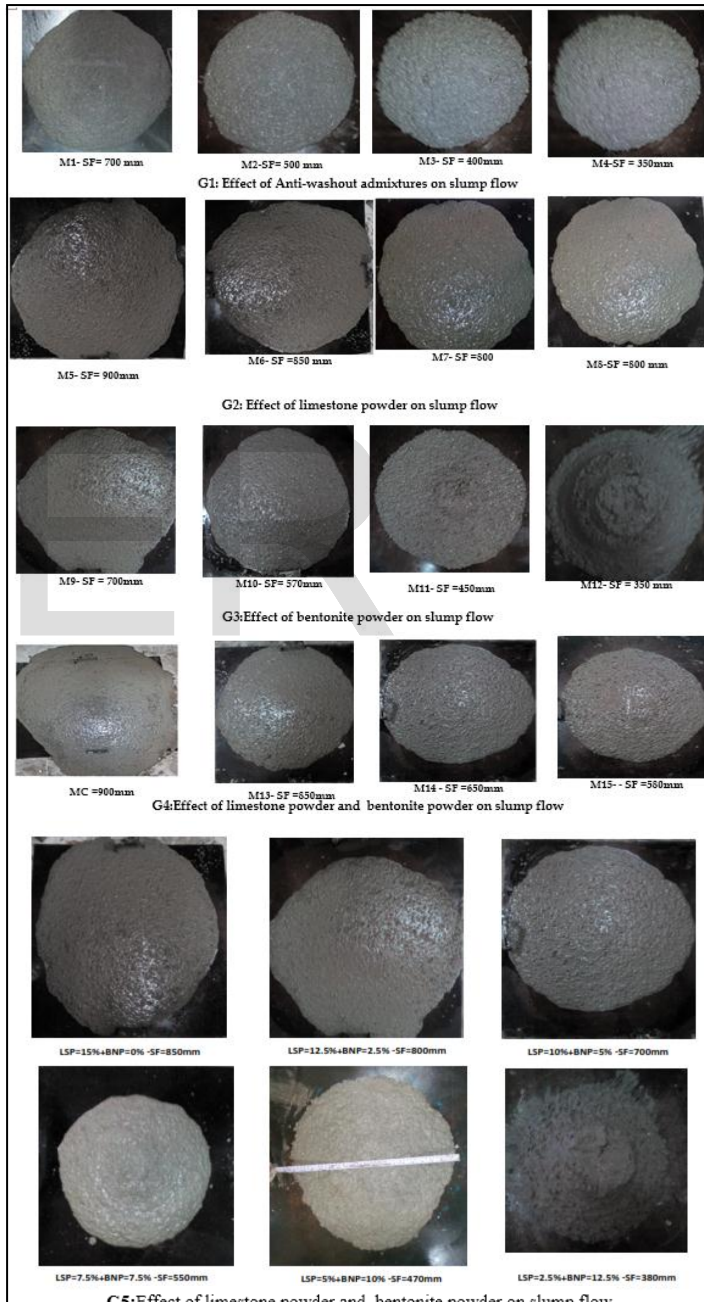

Fig. 3. Slump flow for all mixes

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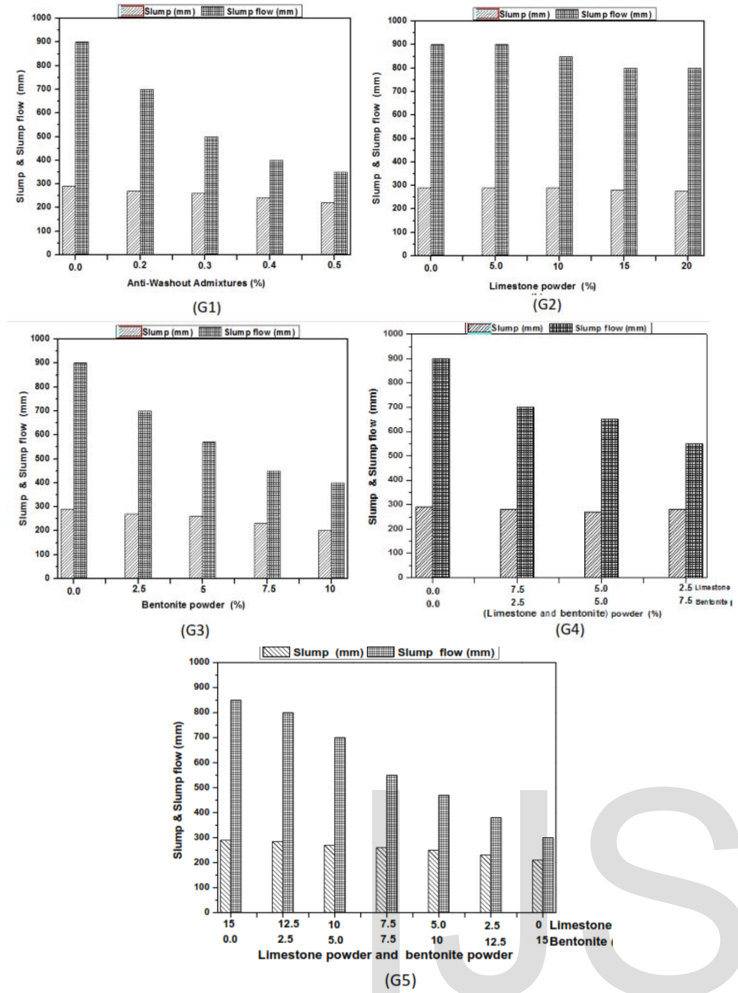

Fig. 4. Slump and slump flow for all mixes

3.1.2 Washout Resistance (Weight Loss and pH Water)

Measured weight loss and pH of all mixes is summarized in Table 3 and Figure 6. The effect of AWA on weight loss and pH can be observed in Figure 5-G1 and 8-G1 regarding concrete mixes group one as the weight loss and pH decreased with the increase of AWA dosage. For instance, as a result of changing AWA from 0.0% to 0.5% by weight of cement, the weight loss decreased from 28% to 0.0% corresponding to pH from 10.9 to 7.8 respectively. The effect of limestone powder on weight loss and pH is that the weight loss and pH slightly decreased as limestone powder increased. For example, as it can be observed in Figure 5-G2 and 6-G2 regarding concrete mixes group two, due to the changes of limestone powder from 0.0% to 20% by weight of cement, the weight loss changed from 28 % to 13% corresponding to pH from 10.9 to 9.8 respectively. On the other hand, the weight loss decreased as bent onite powder increased. For example, as it can be observed in Figure 5-G3 and 6-G3 regarding concrete mixes group three, due to the changes of bentonite powder from 0.0% to 10% by weight of cement, the weight loss changed from 28% to 2.1%.

Fig. 5. Weight loss for all mixes

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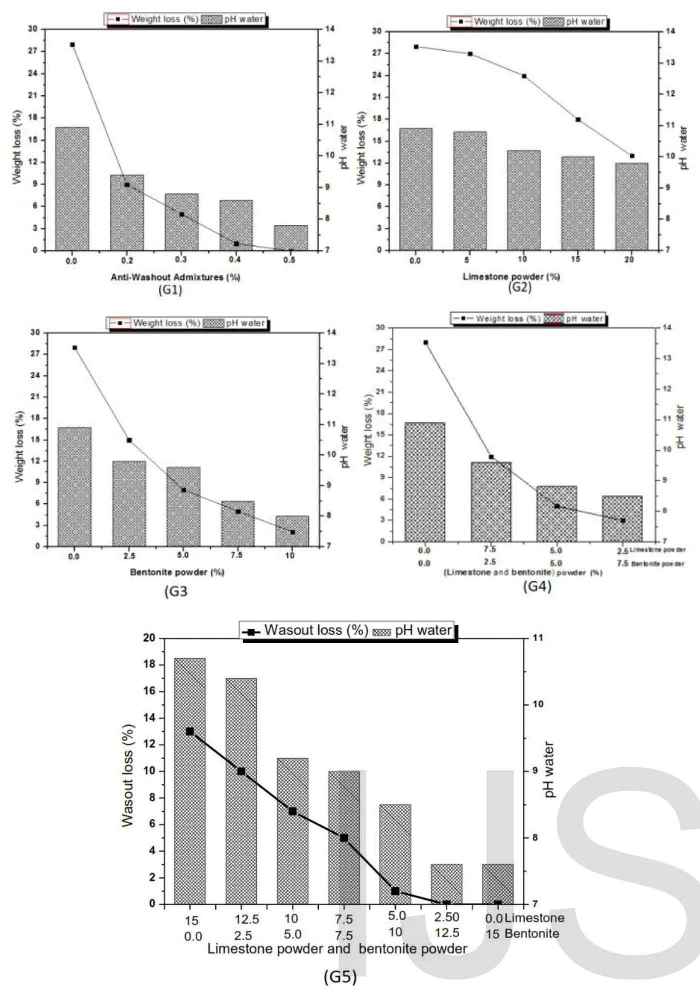

Figure 6: Weight loss and pH water for all mixes

3.1.3 Segregation Ratio

Measured segregation ratio of all mixes is summarized in Table 3 and Figure 7. The effect of the AWA on segregation ratio can be observed in Figure 7-G1 regarding concrete mixes group one as the segregation ratio decreased with the increase of AWA dosage. For instance, as a result of changing AWA from 0.0% to 0.5%, segregation ratio changed from 33% to 0% respectively. The effect of limestone powder on segregation ratio is that the segregation ratio decreased as limestone powder increased. For example, as it can be observed in Figure 7-G2 regarding concrete mixes group two, due to the changes of limestone powder from 0.0% to 20% by weight of cement, the segregation ratio changed from 33 % to 12% respectively. The effect of bentonite powder on segregation ratio is that the segregation ratio decreased as bentonite powder increased. For example, as it can be observed in Figure 7-G3 regarding concrete mixes group three, due to the changes of bentonite powder from 0.0% to 10% by weight of cement, the segregation ratio changed from 33 % to 2% respectively. Figure 7-G4. In the mixes prepared with LSP and BNP as fine materials, the content of LSP changed from 7.5 to 2.5% by weight of cement, while BNP content was changed from 2.5 to 7.5% according to the change of LSP content. Thus, the total content of both LSP plus BNP is always 10% by weight of cement. Test results indicated that the use of 2.5% of LSP (7.5% BNP) has a good result of fresh and hardened concrete properties. The recorded segregation ratio was 0.5%.

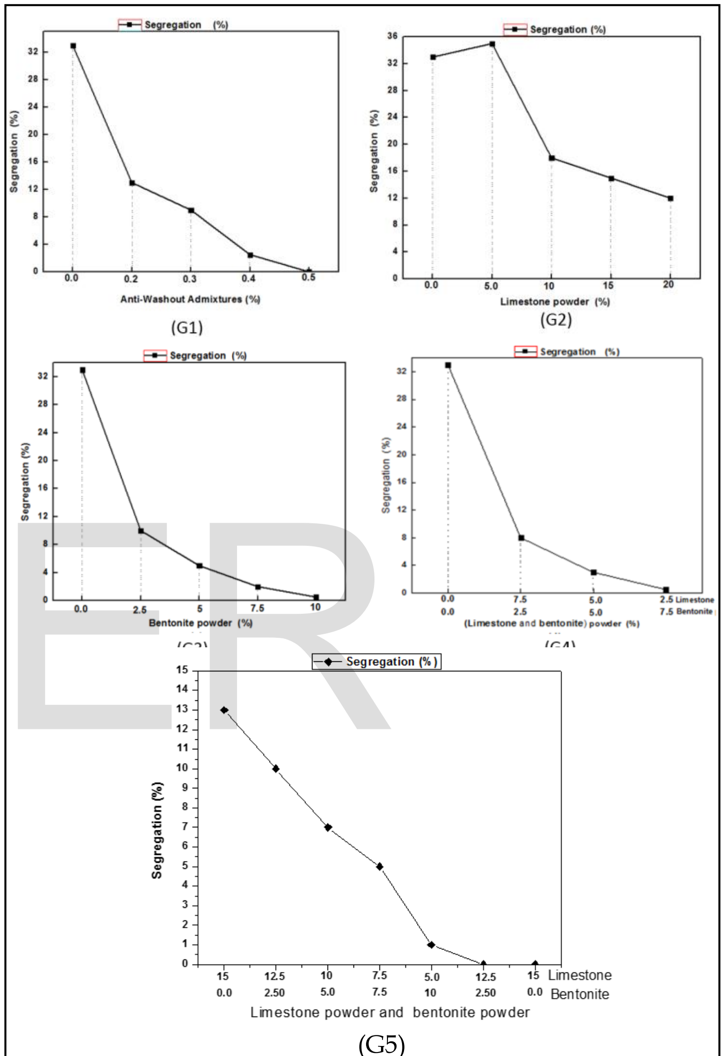

Figure 7: Segregation ratio for all mixes

3.1.4 Air content

The effect of anti-washout admixtures on the air content is summarized in Table 3 and Figure 8-G1 which show that AWA dosage up to 0.5% by wight of cement leads to an increase in the air content. When the dosage of AWA reached about 0% to 5%, the air content incresed up to 52%. As a result of changing AWA from 0.0% to 0.5% by weight of cement, the air content changed from 2.6% to 4% respectively. The effect of limestone powder on air content is that the air content decreased as limestone powder increased. For example, as it can be observed in Figure 8-G2 regarding concrete mixes

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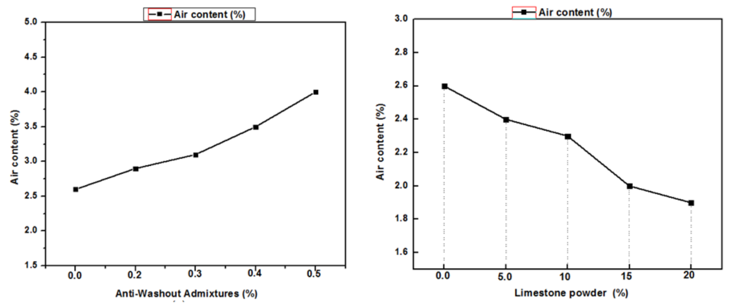
group two, due to the changes of limestone powder from 0.0% to 20% by weight of cement, the air content changed from 2.4 % to 1.9% respectively.



(G1) (G2)

Figure 8: Segregation ratio for all mixes

3.2. Hardened properties

The mechanical properties of underwater concrete were investigated in terms of unit weight and compressive strength at 7 and 28 days. Test specimens that were made underwater are produced by placing concrete into water 500 mm deep. The compressive strength test results for concrete cast underwater were compared with strengths determined on cubes cast normally (in air) and are summarized in Table 4. The strength at each age was measured for three specimens and averaged.

Table 4: Hardened properties of (UWC)

Mix		Concrete mix			Unit Weight	7-day compressive strength			28-day compressive strength		
		AWA (%)	LSP (%)	BN (%)	Kg/m³	F_{OW} N/mm²	F_{UW} N/mm²	F_{UW}/F_{OW} (%)	F_{OW} N/mm²	F_{UW} N/mm²	F_{UW}/F_{OW} (%)
Con.	M.C.	0	-	-	2252	37.5	15.7	41.8	50	20.4	40.9
G1	M1	0.2	-	-	2313	35.7	29.9	83.7	51.1	38.9	76.1
	M2	0.3	-	-	2325	33	30	90.9	48.6	44.4	91.4
	M3	0.4	-	-	2328	32	34	106.2	46	45.8	99.6
	M4	0.5	-	-	2370	30	33	110	45.1	46	102
G2	M5	-	5	-	2210	39	16.5	42.3	51.5	23	44.7
	M6	-	10	-	2290	40	21	52.5	52	27	51.9
	M7	-	15	-	2260	37	24	64.9	50	32	64
	M8	-	20	-	2300	35	28.5	81.4	49	37	75.5
G3	M9	-	-	2.5	2423	42	30	75	55	40	72.7
	M10	-	-	5	2408	45	38	84.4	56.5	45.2	80
	M11	-	-	7.5	2364	37	33	89.2	50	45.5	91
	M12	-	-	10	2325	38	35	92.1	49	47.5	97
G4	M13	-	7.5	2.5	2370	46	37	80.4	58	44	75.8
	M14	-	5	5	2352	39	36	92.3	51	46	90
	M15	-	2.5	7.5	2350	43	39.5	91.8	55	52.2	94.9
G5	M16	-	15	0	2325	39	17	39.5	58	26.1	45
	M17	-	12.5	2.5	2352	40	28	70	60	41.4	69
	M18	-	10	5	2370	38	27.7	73	58	44	76
	M19	-	7.5	7.5	2364	36	27.7	77	55	42.9	78
	M20	-	5	10	2408	34	27.8	82	52	44.2	85
	M21	-	2.5	12.5	2423	33	30	91	50	47.5	95
	M22	-	0	15	2450	30	28.8	96	49	48	98

3.2.1 Compressive strength

Figure 9-G1 shows the compressive strength at 28-days for casting in air and casting in water specimens at different anti-washout admixtures, limestone powder and bentonite powder. The effect of the anti-washout admixtures on compressive strength shows that test specimens made in air (casting in air) are lowered by increasing the amount of AWA. This is attributed to the amount of AWA increased that can result in an increase in air-entrainment that will tend to lower the compressive strength. For instance, as a result of changing AWA from 0.0% to 0.5%, the compressive strength changed from 50 N/mm² to 45.1 N/mm² respectively. On the other hand, the compressive strength of test specimens made in water (casted in water) increased by an increase of the amount of AWA. For example, because of changing AWA from 0.0 % to 5% by weight of cement, the compressive strength changed from 20.4 N/mm² to 46 N/mm² respectively. This also agrees with the results given in [9-10]. It is attributed to the contamination of fresh concrete resulting from water erosion. Figure 9-G2 shows the effect of limestone powder on the compressive strength of test specimens made in water (casted in water) increased by an increase of the amount of limestone powder. For example, because of changing limestone powder from 0.0% to 20% by weight of cement, the compressive strength changed from 20.4 N/mm² to 37 N/mm² respectively. Figure 9-G3 indicates that the effect of bentonite powder on the compressive strength of test specimens made in water (casted in water) increased by an increase of the amount of bentonite powder. For example, because of changing bentonite powder from 0.0% to 10% by weight of cement, the compressive strength changed from 20.4 N/mm² to 47.5 N/mm² respectively. Figure 9-G4 shows that two types of fine materials were used (LSP and BNP). Thus, the total content of both LSP plus BNP is always 10% by weight of cement. Test results indicated that the use of 2.5% of LSP (7.5% BNP) gives good results of hardened concrete properties that the recorded compressive strength cast in water is 52.N/mm² corresponding to cast in air 55.N/mm². Figure 9-G5, the use of 7.5% of LSP plus 7.5% of BNP produced UWC was achieve in fresh and hardened.

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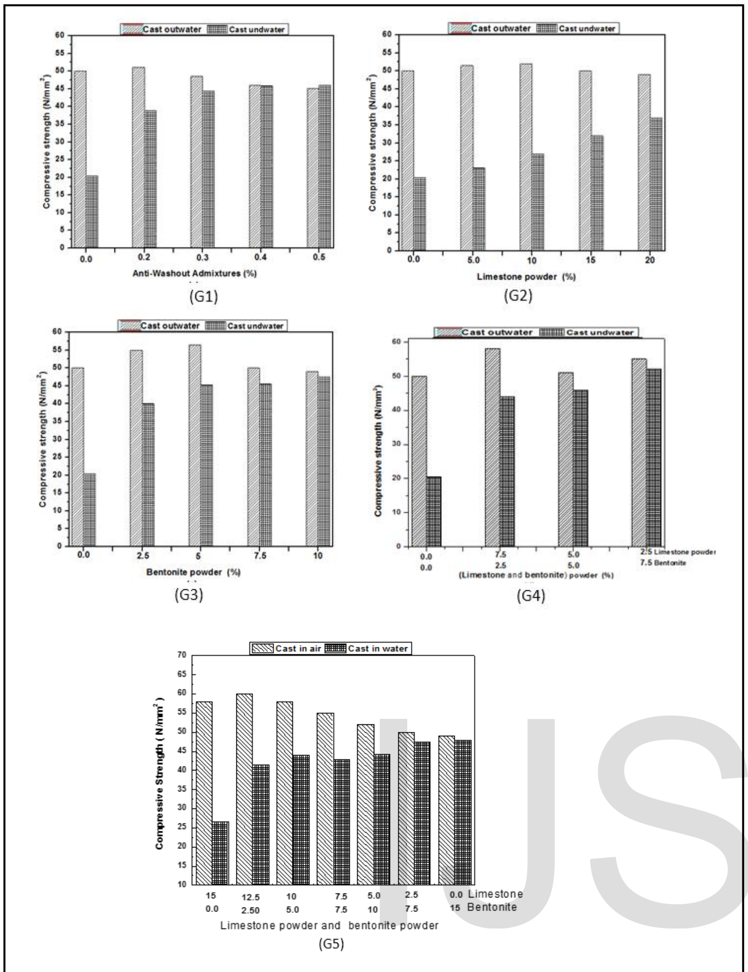

Figure 9: Compressive strength for all mixes

3.2.2 Relation between residual compressive strength and weight loss

Relation between the residual compressive strength of the water to the air placed concrete specimens and weight loss of all the investigated mixes. The residual strength is presented for 28-days ages accepted criterion specified by The Japanese society of civil engineers (JSCE) standards require that the compressive strength of underwater-casted specimens attains a minimum of 70% for the strength of specimens casted above water [4]. Figure 10 shows the graphical relation between residual compressive strength and weight loss. It can be noted that the residual compressive strength increases with weight loss decrease. This also agrees with the results given in [12-13].

From Figure 10-G1, it is indicated that the residual compressive strength is directly dependent on weight loss. For example, adding AWA reduced weight loss from 28% to 0%; hence, residual compressive strength increased from 40.9% to 102% respectively for different AWA. This can be attributed to the relative loss of cement paste associated with a potential infiltration of water inside the concrete. This suggests that concrete parameters should be appropriately selected and proportioned to reduce weight losses and thereby maintain adequate relative compressive strength [14].

Another assessment method for the efficiency of limestone powder is the measurement of residual compressive strength. Figure 10-G2 shows that residual compressive strength of test specimens made underwater to those made in air (out of water) increases as the amount of limestone powder increases. On average, for mixes containing 0.0, 5, 10, 15 and 20% of limestone powder, residual compressive strength ratios were 40.9, 44.7, 51.9, 64 and 75.5% respectively. The effect of bentonite powder on residual compressive strength is that the decrease in weight loss due to higher bentonite powder was found to lead to a net increase in residual compressive strength. From Figure 10-G3, it is indicated that the strength of UWC is directly dependent on weight loss. For example, for mixes containing 0.0, 2.5, 5, 7.5 and 10% of bentonite powder, residual compressive strength was 40.9, 72.2, 80, 91 and 97% respectively.

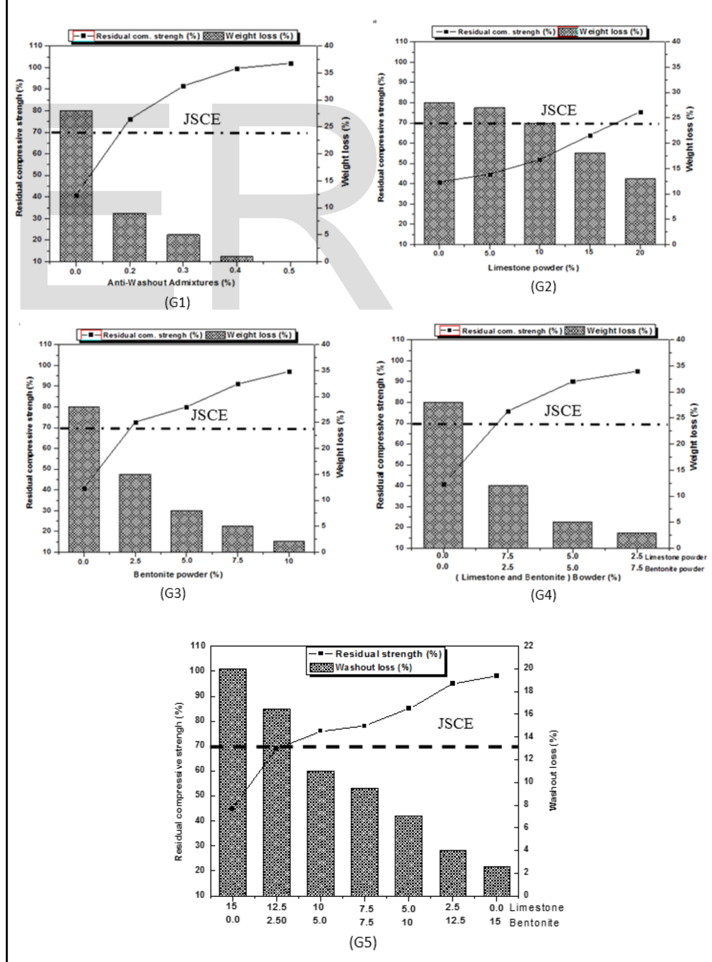

Figure 10: Relation between the residual compressive strength and weight loss for all mixes

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Microstructure Analysis

Scanning electroscope imaging analyses on concrete samples, X-ray diffraction analyses and energy dispersive X-ray spectroscopy analyses on underwater concrete. A Stereoscan Cambridge 1000 Scanning Electron Microscopy (SEM) was used to investigate the morphology of the material. The analyses were performed on samples extracted from Mix 3 concrete specimens. Were detected in the crystallographic structure. According to the images presented in Figure 11 for underwater concrete which shows strong bond between the aggregate and paste which enhance the compressive strength. Figure 11, shows the main oxides for the tested samples. Test results show good consistency of the main oxides' composition of the produced UWC during the period of production tested. The UWC contains around 18.43% CaO, 17.68% SiO2 and 1.88% Mg.

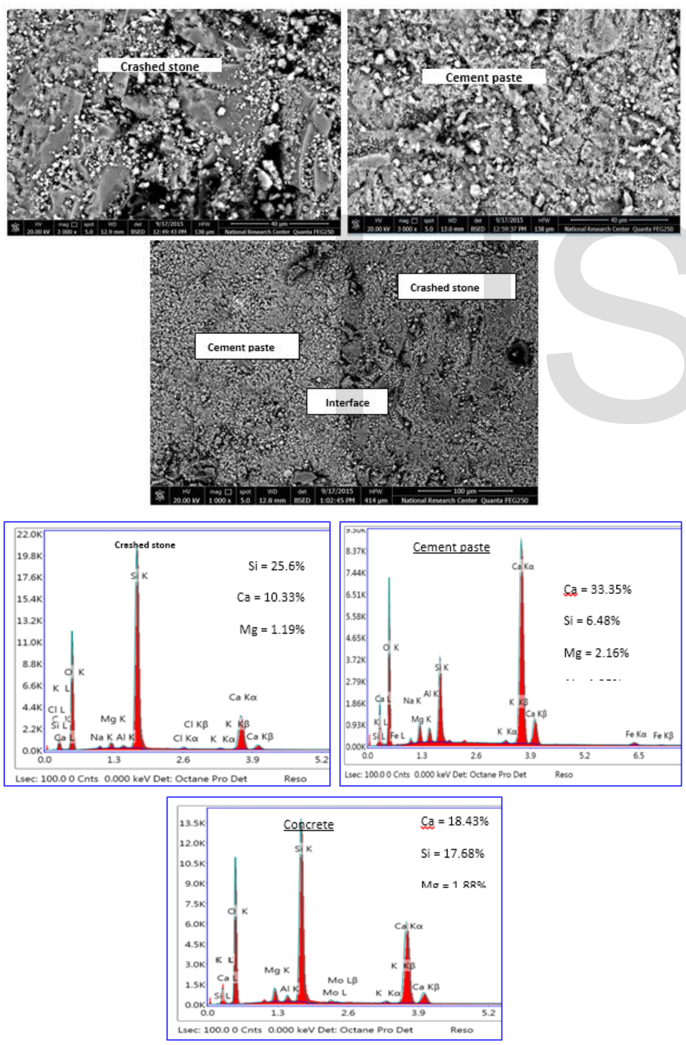

Figure 10: Photomicrograph and Oxides weight percentage content in UWC with crashed stone, detected after EDS-EDAX analysis.

4. Conclusions

Based on the results of experimental work presented in this paper, the following conclusions are drawn:

1-The employed ternary blend of cement, flay ash, and silica fume and with the inclusion of lime stone powder or bentonite powder successfully enhanced the flowing properties of the developed concrete mixtures. That is because they have different grain sizes and shapes which would be reflected on minimizing the porosity, better backing of the fines, and probably the interlocking action.

2- Slump flow of underwater concrete without AWA decreased as bentonite powder ratio increased. As a result of changing bentonite powder from 0.0 to 10% by weight of cement, the slump flow changed from 900 to 350 mm respectively.

3- For a given workability, segregation ratio and weight loss increase for UWC non AWA. The use of higher percentages of bentonite powder and silica fume resulted in lower segregation ratio and weight loss.

4- The incorporation of AWA appears to exhibit remarkable decreases in segregation ratio and weight loss. The higher AWA concentration resulted in lower segregation ratio and weight loss, indicating that the presence of AWA tends to increase the viscosity of the mixes.

5- Antiwashout underwater concrete has the required filling and self-leveling properties, no-segregation ratio or reducing compressive strength of concrete. Antiwashout underwater concrete with loss of mass by washout gets 67%-100%. The ratio of strength in water to gained strength in air gets 83.7-110%.

6- It was observed that the concrete mixes which contain silica fume (G2) show less residual compressive strength compared with the other four groups (G1,G3 ,G4 and G5) .

7- All concrete mixes of groups (G1, G3, G4 and G5) attained the minimum residual compressive strength recommended by the JSCE.

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