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Comparison Between Utilization of Industrial Waste Steel Slag as Aggregates and Natural Aggregates in Underwater Self-compacting Concrete

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Abstract

An environmentally friendly approach to the disposal of waste materials, a difficult issue to cope with in today’s world, would only be possible through a useful recycling process. Steel slag is a byproduct of metal smelting and hundreds of tons of it are produced every year all over the world in the process of refining metals and making alloys. Coarse aggregates is one of these factors that have a significant influence on underwater self-compacting concrete (UWSCC). The work involves three groups with the total number of twenty seven underwater-concrete mixes. First group uses gravel, the second group uses steel slag, and the third group uses crushed dolomite. The test program was designed and arranged to consider the effect of four different parameters as follows; water binder ratio (w/b), high range water-reducing (HRWR) dosage, fine to coarse aggregates ratio and maximum size aggregates. The concrete mixtures were tested for slump, slump flow, slump flow time ($T_{50\ cm}$), V-funnel, L-box, GTM screen stability, washout loss method that is the plunge test CRDC61 which is widely used in North America, and compressive strength. The results show that UWSCC with industrial waste steel slag as aggregates has higher values of compressive strength and unit weight compared to UWSCC with natural aggregates.

Keywords:steel slag, crushed dolomite, gravel, underwater concrete, Washout loss.

1. Introduction

In recent years, as concrete structures in harbor, bridge, and marine construction have become larger in scale, the need for anti washout underwater concretes to assure correct underwater placement has been increased [1].Underwater placement of concrete can present major problems for contractors and can have a significant impact on the practicalities of site work.

The key to successful underwater placement is to avoid both segregation of the mixture and the washing out of the cement paste. Underwater-cast concrete must be proportioned to be highly flowable in order to spread into place without consolidation and must exhibit adequate stability to reduce segregation and water dilution [2].

The characteristic feature of the composition of underwater concrete mixes is the necessity of using anti washout admixtures (AWA). The AWA admixtures improve the cohesion of the concrete mix and prevent bleeding and segregation of the mix and binder washout during underwater concreting [3-4]. The typical in situ residual compressive strength of concrete with adequate anti washout properties is generally greater than 0.70 [5]. 50% - 70% of self-consolidated UWC depends on turbulence of water and location of extracted cores for strength testing [6]. The compressive strength ratio of test specimens made underwater to those made in air increased as the amount of AWA increased. As a result of changing AWA 0% - 0.5% by cement weight, the relative compressive strength was 36% - 103% corresponding to a washout loss 19% - 3.7% respectively [7].

The drop in UWC strength can be attributed to a combination of factors such as washing out of fine cementitious particles and exceeding the specified water-to-cementitious materials ratio (w/cm), agitation of wet concrete by the action of surrounding water, segregation of aggregates during placement, hydrostatic water pressure, erosion of concrete surfaces, and improper consolidation [8-9]. The increase in demand for the ingredients of concrete is met by partial replacement of materials by the waste materials which are obtained by means of various industries. Slag is a byproduct of metal smelting and hundreds of tons of it are produced every year all over the world in the process of refining metals and making alloys. Like other industrial byproducts, slag actually has many uses, and rarely goes to waste. It appears in concrete, aggregate road materials such as ballast, and is sometimes used as a component of phosphate fertilizer. In appearance, slag looks like a loose collection of aggregate with lumps of varying sizes. [10] The used electric arc furnace steel slag (EAFSS) in concrete aggregate helps enhancing the cohesion between the aggregate particles and the surrounded cement mortar as well as the higher hardness of (EAFSS) due to the surface texture and shape [11].

The unit weight of underwater concrete containing steel slag as coarse aggregate varies from 2400 kg/m^3 to 2655 kg/m^3. The higher unit weight of the steel slag coarse aggregate concrete attributes to higher specific gravity of the steel slag coarse aggregate [7].

The main objective of this paper is the comparison between utilization of industrial waste steel slag as aggregate and natural aggregate (crushed dolomite and gravel) in underwater self-compacting concrete. The paper aimed to highlight the effect of water binder ratio, superplasticizer dosage and maximum size of aggregate on the fresh and hardened properties of UWSCC.

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. The chemical compositions of cement can be observed in Table 1. A 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 high-range water reducing (HRWR) of 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.

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. 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. In this study the three types of coarse aggregate are industrial waste steel slag as aggregate, crushed dolomite and gravel with a maximum size of 10 mm and specific gravity (3.5, 2.65 and 2.68) and absorption (1.02, 2.05 and 0.6%), respectively. Figure 1 shows the used steel slag.

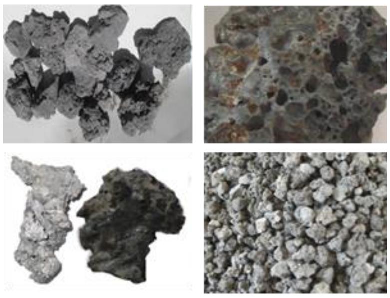


Figure 1: Steel slag aggregate used.

TABLE 1: CHEMICAL AND PROPERTIES of USED CEMENT, SILICA FUME, LIME STONE POWDER and STEEL SLAG COARSE AGGREGATES

Properties	Cement by co. (%)	Silica fume co. (%)	Lime stone co. (%)	Steel slag co. (%)
SiO_2	21.0	96.00	6.49	13.10
Al_2O_3	6.10	1.10	0.76	5.51
Fe_2O_3	6.10	1.45	0.36	36.80
CaO	61.5	1.20	34.95	33.0
MgO	3.8	0.18	14.44	5.030
K_2O	0.3	1.20	0.10	-
Na_2O	0.4	0.45	-	-
SO_3	2.5	0.25	0.67	4.180

2.2 Mix design, casting, and mixing procedure

There were three groups with the total number of twenty seven underwater concrete mixes. First group uses gravel, the second group uses steel slag, and the third group uses crushed dolomite. The test program was designed and arranged to consider the effect of four different parameters as follows; water binder ratio (0.35, 0.45 and 0.50), high-range water-reducing dosage (2% , 3% and 4%) by weight of cement, the fine to coarse aggregate ratio (50:50 , 45:55 and 40: 60) and maximum size of aggregate (5 mm ,10 mm and 20 mm). Table 2 demonstrates the proportioning of various concrete mixes materials. Furthermore, all concrete mixes involve silica fume, lime stone powder and anti-washout admixtures (15%, 15% and 0.3%) respectively by weight of cement.

Figure 2 shows underwater casting of concrete samples. Twelve 150 mm cubes were casted from each mix 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 the air and under the 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).

All batches were mixed according to the same procedure in an open pan mixer. The mixing sequence consisted of placing the wet coarse aggregates and fine aggregates in the mixer and mixing for 1 min., the cement and silica fume were then added and mixed for a few seconds to obtain a homogeneous mix. The (AWA) powder was distributed into the mix followed by the adherence of water and HRWR. Once all mixture constituents were added, the concrete was mixed for 3 min. following a 1 min rest and the mixing was resumed for two additional l min.

TABLE 2: CONCRETE MIX PROPORTIONS

Groups		Mix	Cement (kg/m^3)	W/b	HRWR (%)	Aggregates	AWA (%)	LSP (%)	SF (%)
1	Gravel	M1 M2 M3	500	0.35 0.45 0.50	4	R1	0.3	15	15
		M4 M5	500	0.353	2 3	R1	0.3	15	15
		M6 M7	500	0.353	4	R2 R3	0.3	15	15
		M8 M9	500	0.353	4	R1* R1**	0.3	15	15
2	Steel slag	M10 M11 M12	500	0.35 0.45 0.50	4	R1	0.3	15	15
		M13 M14	500	0.353	2 3	R1	0.3	15	15
		M15 M16	500	0.353	4	R2 R3	0.3	15	15
		M17 M18	500	0.353	4	R1* R1**	0.3	15	15
3	Crushed dolomite	M19 M20 M21	500	0.35 0.45 0.50	4	R1	0.3	15	15
		M22 M23	500	0.353	2 3	R1	0.3	15	15
		M24 M25	500	0.353	4	R2 R3	0.3	15	15
		M26 M27	500	0.353	4	R1* R1**	0.3	15	15

Where

W/b: water to binder ratio (cement + SF+ LSP) HRWR: High-range water reducing

AWA: Anti-washout admixtures R1 = 50:50 = 10 mm R1* = 5mm R1** = 20mm R2=45:55 R3=40:60 LSP: Lime stone powder S.F: Silica fume

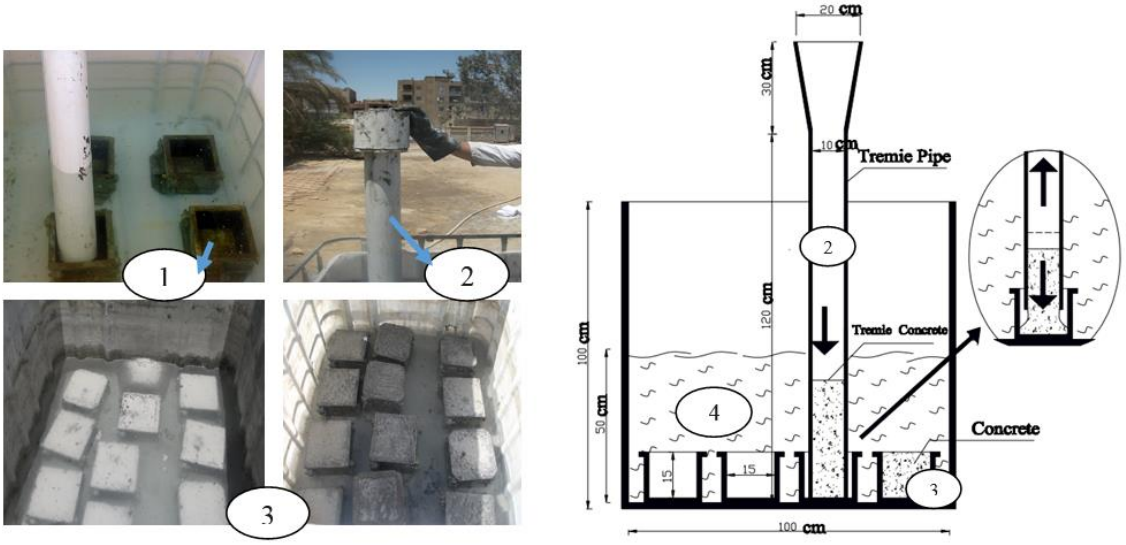


Figure 2 : Underwater casting of concrete samples

1- 150 mm cubic moulds before casting; 2- Tremie pipe 100 mm; 3- 150 mm cubic moulds after casting; 4- water

2.3 Test methods for UWSCC

In the fresh state, the tests are slump, slump flow, slump flow time $_{(T\text{-}500),}$ V-funnel, L-box, GTM screen stability and washout loss of UWSCC determined using the CRD C61 test method. This test consists of subjecting a fresh concrete sample placed in a perforated basket to free fall in a 1.7-m high column of water [12].

After 15 sec. at the bottom of the test tube, the sample is retrieved at constant speed of 0.5 m/s and measured to determine washout mass loss. Cumulative washout losses after three drops in water are reported. Around 2 kg are normally used when testing washout loss as per CRD C61 test. All test methods were used for the assessment of the fresh properties of UWSCC in this study while compressive test was used for studying hardened properties.

3. Results and discussion

3.1 Fresh properties

In the fresh state, the tests are slump, slump flow, slump flow time $_{(T\text{-}500)}$, V-funnel, L-box, GTM screen stability and washout loss. The measured fresh properties of all mixes are summarized in Table 3.

TABLE 3: FRESH PROPERTIES OF (UWSCC)

Groups		Mix no	Slump (mm)	Slump flow (mm)	$T_{50\ cm}$ (s)	L-Box (%)	GTM screen stability (%)	V-Funnel FT_0 (s)	V-Funnel FT_{5min} (s)	CRD C61 Washout loss (%)
1	Gravel	M1	280	650	7	0.95	9	9	11	5.2
		M2	290	850	1	1	17	3	4	14
		M3	290	950	1	1	30	2	3	27
		M4	260	500	10	0.85	4	12	16	3
		M5	270	600	9	0.9	5	12	13	4.1
		M6	290	670	4	0.9	11	7	8	6.5
		M7	290	700	2	0.87	14	6	7	9.8
		M8	270	630	10	1	5	10	13	1.5
		M9	280	670	2	0.5	23	7	8	8.4
2	Steel slag	M10	270	550	15	0.81	12	12	14	2.5
		M11	280	750	4	1	18	4	7	11.4
		M12	290	850	2	1	35	2	4	19
		M13	230	450	Non	0.75	4.5	19	20	1
		M14	250	500	18	0.8	6	15	17	2
		M15	270	600	6	0.75	15	11	13	5.3
		M16	280	670	4	0.6	17	9	11	7.8
		M17	260	500	20	1	7	22	25	0.85
		M18	280	600	4	0.2	28.7	Non	Non	4
3	Crushed dolomite	M19	270	590	10	0.85	5	11	12	2.2
		M20	290	800	2	1	12	3	5	9.4
		M21	290	900	1	1	27	2	4	12.5
		M22	250	500	16	0.8	3	16	17	0.5
		M23	260	550	12	0.85	4.5	14	17	1.5
		M24	280	620	5	0.8	9	8	9	4.5
		M25	290	680	3	0.76	12	8	8	6.2
		M26	270	550	12	1	3	12	14	0.5
		M27	280	650	3	0.4	13.6	9	10	5.5

3.1.1. Slump, slump flow and T_{50cm}

Results of the investigations on fresh concrete properties of all SCUWC are illustrated in Table 3. The slump flow of the SCUWC was in the range of 450 – 950 mm. In Figure 3, the results show that gravel and crushed dolomite in the mixes gave higher slump, slump flow and T_{50cm} than steel slag in the mixes.

This behavior attributed to the smooth texture of the surface of gravel and weight of steel slag aggregate to be more than that of gravel and crushed dolomite aggregates. The effect of w/b ratio on slump and slump flow is that totally, slump flow increased as w/b ratio increased due to the higher free water content. For instance, as it can be observed in Figure 4 regarding concrete mixes group two, due to the changes of w/b ratio from 0.35 to 0.50 by weight binder ratio, the slump flow changed from 550 to 850 mm respectively.

Table 3 indicates that the T_{50cm} of mixes with 5mm maximum size of coarse aggregate was less than the T_{50cm} of mixes with 10mm and 20mm maximum size of coarse aggregates. This agrees with the study carried out by [13-14].

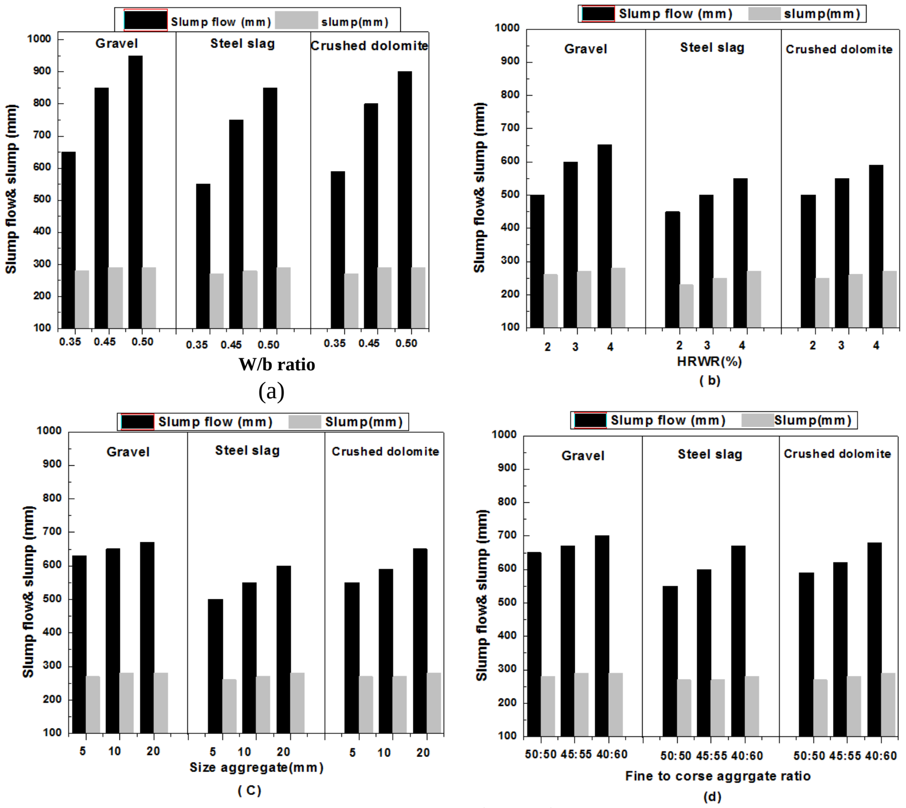


Figure 3: Slump and slump flow for all mixes

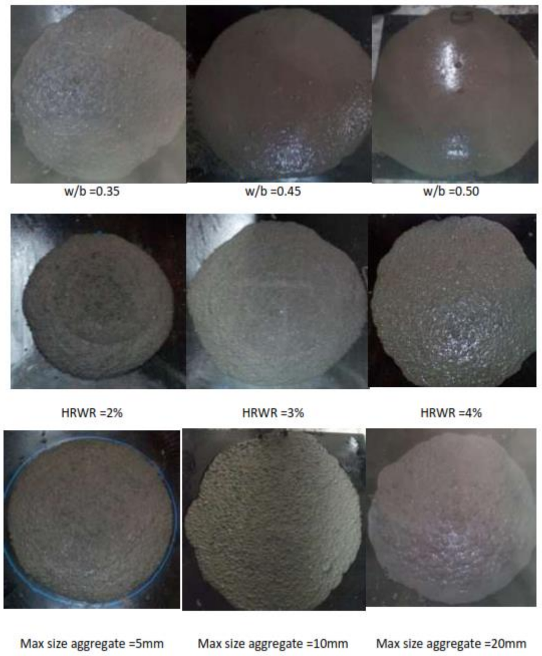


Figure 4: Slump flow for concrete mixes group two (steel slag)

3.1.2. V- funnel

The values of the V-funnel test (Flow Time (FT)) represent the ability of concrete to flow out of the funnel), while the (FT_{5min}) values represent the same ability but after refilling the funnel and allowing concrete to discharge after 5 minutes from the refilling. The V-funnel test flow times were in the range of 3–25 sec. Figure 5 reveals the influence of the maximum size of coarse aggregates on FT_0 and FT_{5min} values. It can be seen from the figure that the larger maximum size 20mm of steel slag coarse aggregates has led to observing blocking and segregation. This is due to being the attributed weight of steel slag aggregates more than that of gravel and crushed dolomite aggregates.

From the test results presented in Figure 5, it is noticed that the mixes made from gravel have values of FT_0 and FT_{5min} less than the mixes made from steel slag and crushed dolomite. For all SCUWC mixtures, FT_0 and FT_{5min} values decreased with the decrease in w/b ratio, HRWR and maximum size of aggregates. Enhancement in this case is attributed to the use of AWA which retains part of mixing water and increases viscosity of the liquid phase of concrete.

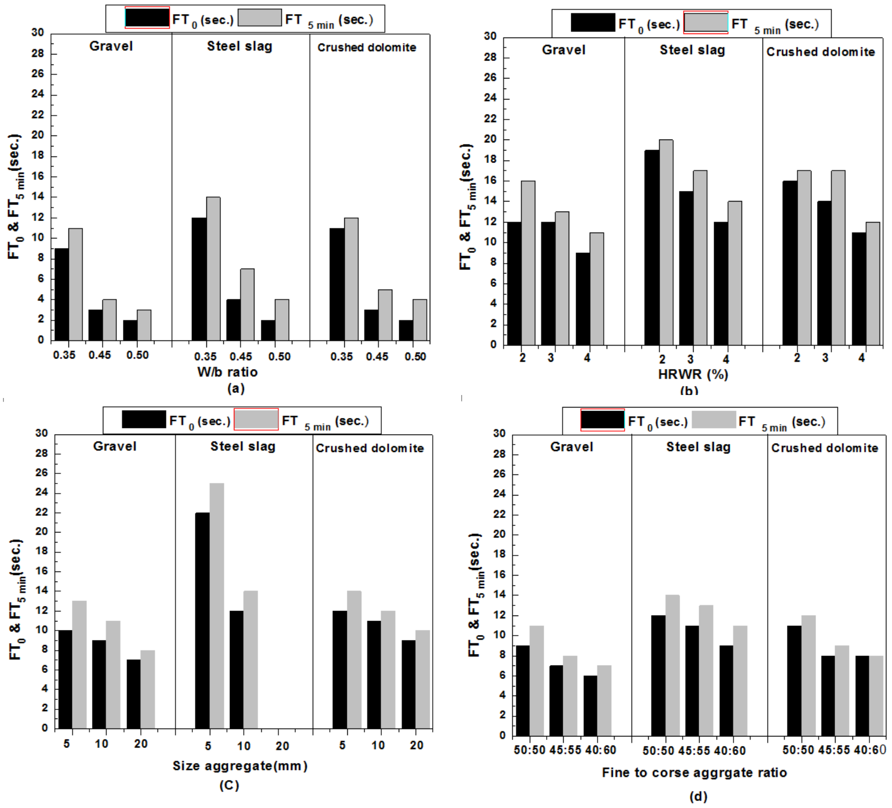


Figure 5: FT_0 and $FT_{5\ min}$ (sec.) for all mixes.

3.1.3. L –box

L-box is used to measure the filling ability and passing ability of UWSCC mixes. Values of (H_2/H_1) represent the blocking ratio (BR). The L-box test results are showed in Table 4 and Figure 6 showing that the mixes with (20mm) maximum size of coarse aggregates give lower (BR) values of (H_2/H_1) as compared with mixes with the (10mm and 5mm) maximum size of coarse aggregates. This is due to the tendency of the mixes with larger maximum size of coarse aggregates to jam flowing while the mixes with smaller maximum size of coarse aggregates will flow freely without stopping. For instance, as it can be observed in Figure (6-c) regarding concrete mixes group two, due to the change of maximum size of coarse aggregates from 5mm to 20mm, the (H_2/H_1) changes from 1 to 0.2 respectively. Also the mixes made of gravel had higher values of (H_2/H_1) than the mixes made of steel slag aggregates and crushed dolomite due to the smooth texture of the surface of gravel and that the weight of steel slag aggregates is more than that of gravel.

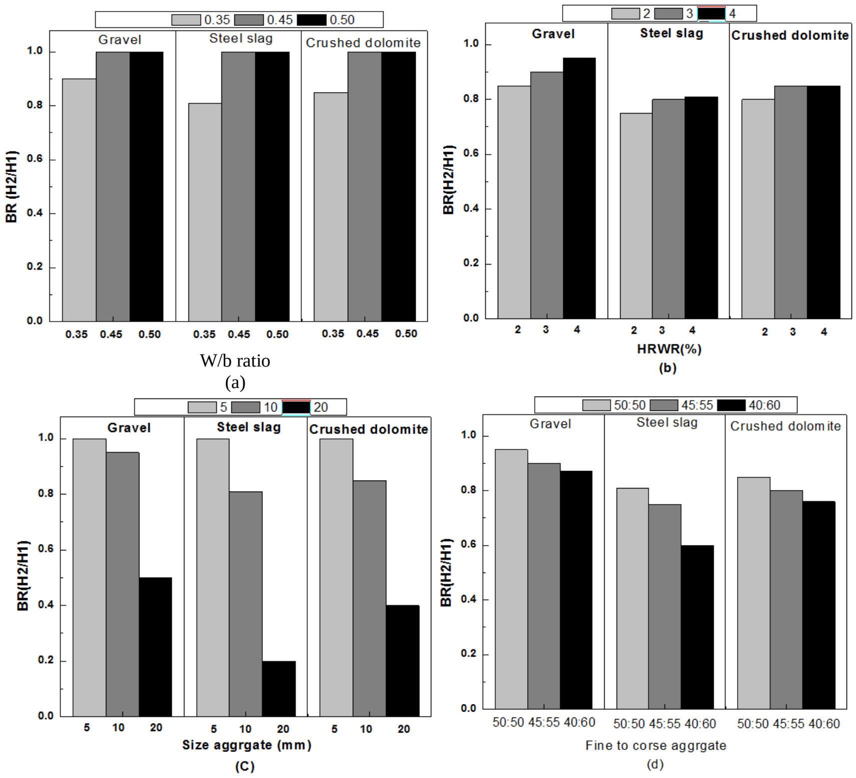


Figure 6: BR(H2/H1) for all mixes.

3.1.4. *Screen stability and washout loss*

Measured segregation resistance and washout loss of all mixes is summarized in Table 3 and Figure 7. The effect of the w/b ratio on segregation resistance and washout loss can be observed in Figure (7-a and 9) regarding concrete mixes group two as the segregation resistance and washout loss increased when the amount of w/b ratio increased. For instance, as a result of changing w/b ratio from 0.35 to 0.50, washout loss changed from 2.5 to 19% corresponding to a segregation from 12 to 35% respectively. The mixtures made with a higher w/b ratio exhibited increased segregation resistance and washout loss due to their higher content of free water which can reduce concrete cohesiveness. This can weaken the ability of the paste to retain free water and suspend solid particles, hence resulting in greater risk of water dilution.

From the test results presented in Figure 7, it is noticed that the mixes made from steel slag have values of segregation resistance lower than the mixes made from gravel and crushed dolomite. This is due to that the attributed weight of steel slag aggregates was more than that of gravel and crushed dolomite aggregates. For example, as a result of changing type aggregates (gravel, steel slag and crushed dolomite), the segregation resistance values were (23%, 28.7% and 13.6%) respectively at maximum size of coarse aggregates 20mm. As shown in Figure (8 and 9), segregation resistance and washout loss values decreased with a decrease in the w/b ratio, HRWR and maximum size of aggregates. Enhancement in this case is attributed to the use of AWA which retains part of mixing water and increases the viscosity of the liquid phase of the concrete.

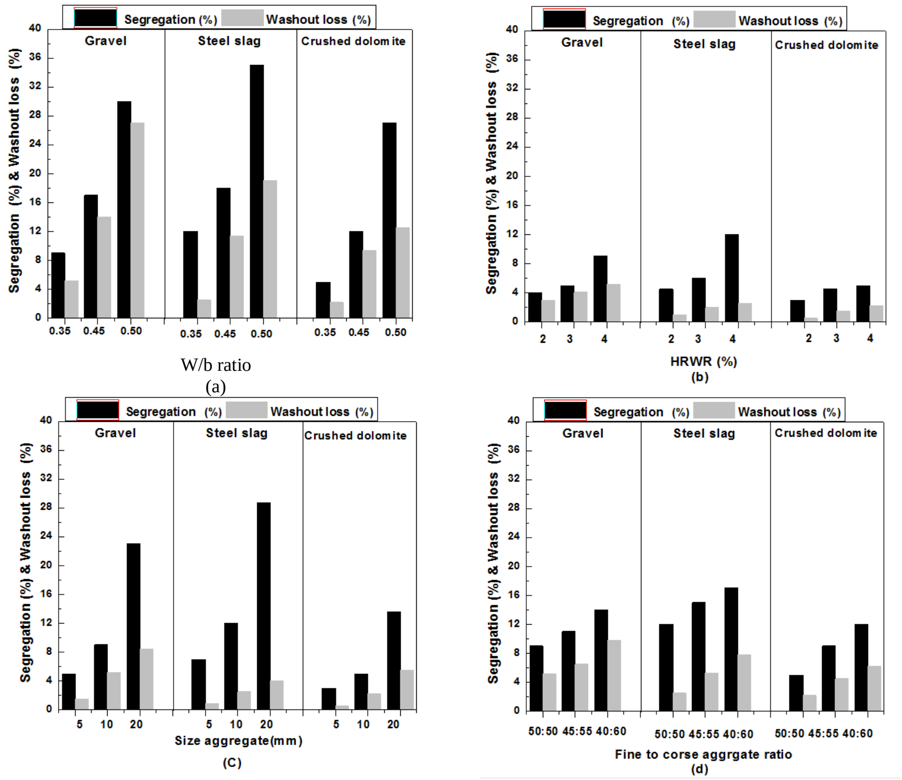


Figure 7: Segregation and washout loss

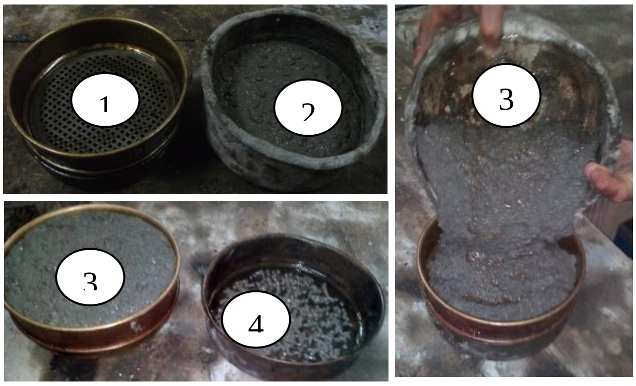


Figure 8: GTM screen stability test method

1- Empty sieve 5 mm; 2- Concrete sample approximately 4,8kg ±0,2kg; 3-Pour all the concrete from the pouring container onto the sieve; 4-the mortar fraction of the sample to flow through the sieve and the sieve pan for a period of 2 minutes.

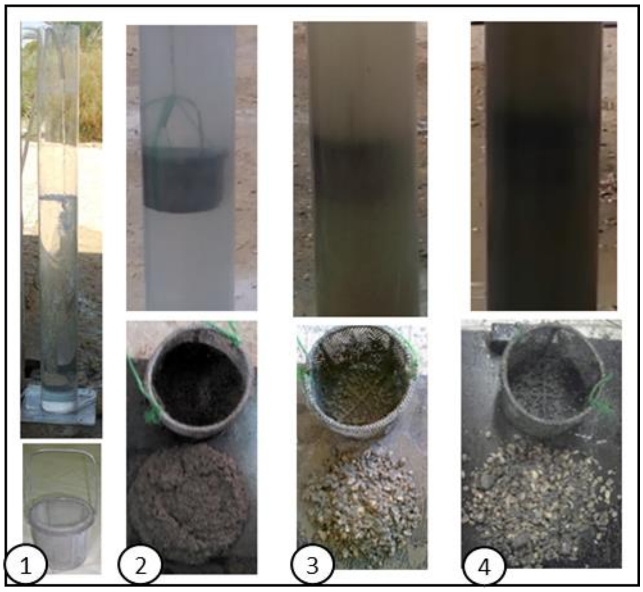


Figure 9: Effect of w/b ratio on washout loss

1- Apparatus; 2- washout loss at w/b ratio 0.35; 3- washout loss at w/b ratio 0.45; 4- washout loss at w/b ratio 0.50

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.

3.2.1. Unit weight

Figure 10 shows the unit weight of hardened concrete. The unit weight of the underwater self-compacting concrete produced by steel slag ranges from 2500 to 2650 kg/m^3 which is higher by 13% compared to the unit weight of the conventional concrete. This is due to that the attributed to the bulk specific gravity of the former aggregates was more than that of the conventional aggregates.

The high unit weight of the produced concrete is an advantageous property where the concrete weight is a key factor, and it is believed that steel slag aggregates will find its way in the near future in several applications in the construction industry such as aggregates for road construction, foundations and underwater concrete.

TABLE 4: HARDENED PROPERTIES OF (UWSCC)

Groups		Mix no	Unit weight (kg/m^3)	Compressive strength at 7day (MPa)			Compressive strength at 28 day (MPa)		
				Cast in air	cast in water	$\frac{\text{water}}{\text{air}}$ (%)	Cast in air	Cast in water	$\frac{\text{water}}{\text{air}}$ (%)
1	Gravel	M1	2267	23.8	23.8	100	37	36	97.2
		M2	2222	15	11	73.3	20	14	70
		M3	2215	10	6	60	11	6.5	59
		M4	2258	25.3	25	99	39.6	40	101
		M5	2267	26.2	21.8	83.2	38	37	97
		M6	2295	23.7	20	84.4	34.5	33	95.6
		M7	2305	22	19	86.3	33	32	96.9
		M8	2275	26.9	27.1	100.7	38.7	41.3	106.7
		M9	2268	22.9	21.1	92.1	35	33	94.3
2	Steel slag	M10	2500	31.7	30.9	99.6	49	51.3	104.7
		M11	2412	26.5	18.9	71.3	30.2	29.5	97.7
		M12	2376	20	13.4	67	26	16.2	62.3
		M13	2495	31.3	30	95.8	51.4	52.7	102.5
		M14	2578	30	28.5	95	51.2	52.2	102
		M15	2620	28.9	27	93.4	42	41.4	98.6
		M16	2650	27.4	24.9	90.9	47	44	93.6
		M17	2570	32	33	103	60	61	101.6
		M18	2581	28	25.8	92.14	48	47	97.9
3	Crushed dolomite	M19	2275	26	25	96.1	44.7	46.7	104.5
		M20	2212	18	16.9	93.8	28.2	20.9	95.4
		M21	2200	16	11	68.75	23	15	65.2
		M22	2262	29	30	103.4	50	51	102
		M23	2275	30.7	31.1	101.3	48	49.5	103.1
		M24	2300	25.8	24.7	95.7	46.7	44.4	95
		M25	2350	23	21	91.3	43	42	97.7
		M26	2110	34	32.5	95.6	58.5	57	97.4
		M27	2281	24	22.5	93.7	46.6	45	97.6

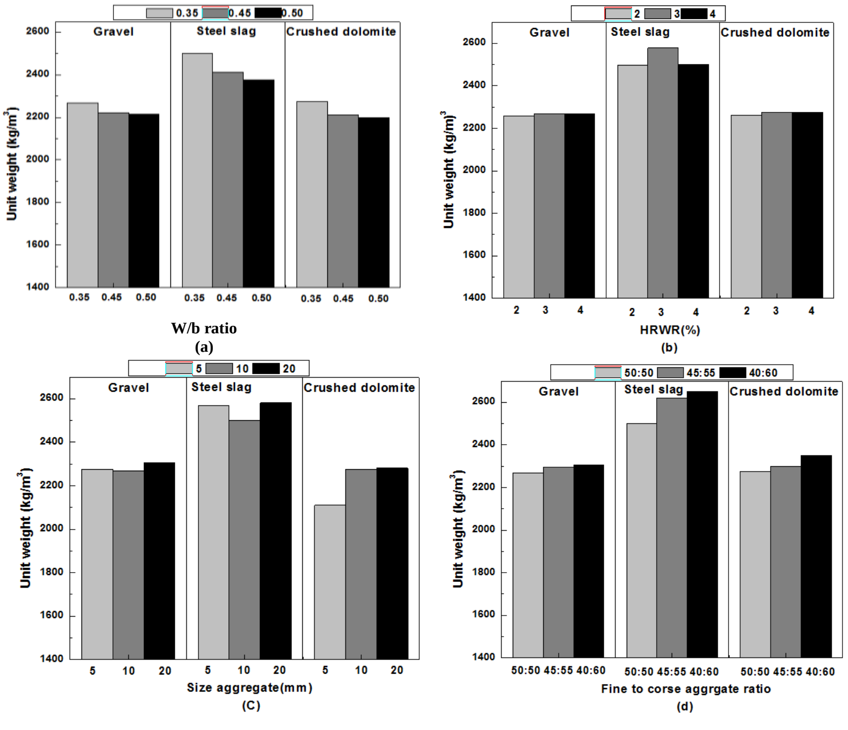


Figure 10: Unit weight of all mixes

3.2.2 Compressive strength

Figure. 11 shows the compressive strength at 28 days for the cast in air and cast in water specimens at different w/b ratio, HRWR dosage, maximum size of aggregates and fine to coarse aggregates ratio. The effect of the w/b ratio on compressive strength is that totally, compressive strength of test specimens made by casting in water decreased as w/b ratio increased. For example, an increase in w/b ratio from 0.35 to 0.50 led to a decrease in compressive strength from 51.3 to 16.2 N/mm^2 for mixtures made with steel slag aggregates.

This can be attributed to their higher content of free water which can reduce concrete's cohesiveness. This can weaken the ability of the paste to retain free water and suspend solid particles, hence resulting in greater risk of water dilution. On the other hand, compressive strength decreased as HRWR dosage increased. For example, an increase in HRWR dosage from 2 to 4% by weight of cement led to a decrease in compressive strength from 51 to 46.7 N/mm^2 for mixtures made with crushed dolomite. This may be attributed to the HRWR dosage which increases flowing of the plastic concrete.

These data indicate that the type of aggregates has a significant effect on the compressive strength of UWSCC. The highest compressive strength was measured in the concrete specimens prepared with steel slag aggregates while the lowest compressive strength was noted in the concrete specimens prepared with gravel and crushed dolomite. For example, after 28 days, the compressive strength of concrete specimens prepared with gravel, crushed dolomite and steel slag aggregates was 43.1, 57 and 61 N/mm^2 respectively. This can be attributed to the strong bond between the aggregates and paste which is stronger. This could be ascribed to the rough and porous surface of the steel slag particles as shown in Figure 1.

From the test results presented in Figure (11-c) regarding the effect of maximum size of coarse aggregates on compressive strength, it can be noticed that the compressive strength of mixes made with the 5mm maximum size of coarse aggregates is higher than the values of mixes made with the 20mm maximum size of coarse aggregates. For example, an increase in maximum size of coarse aggregates from 5mm to 20mm led to a decrease in compressive strength from 61 to 47 N/mm^2 respectively for mixtures made with steel slag aggregates. This is due to the smaller maximum size of coarse aggregates that has the larger surface area that results in a higher bonding strength in the transition zone (ITZ) around aggregates particles when concrete is under loading.

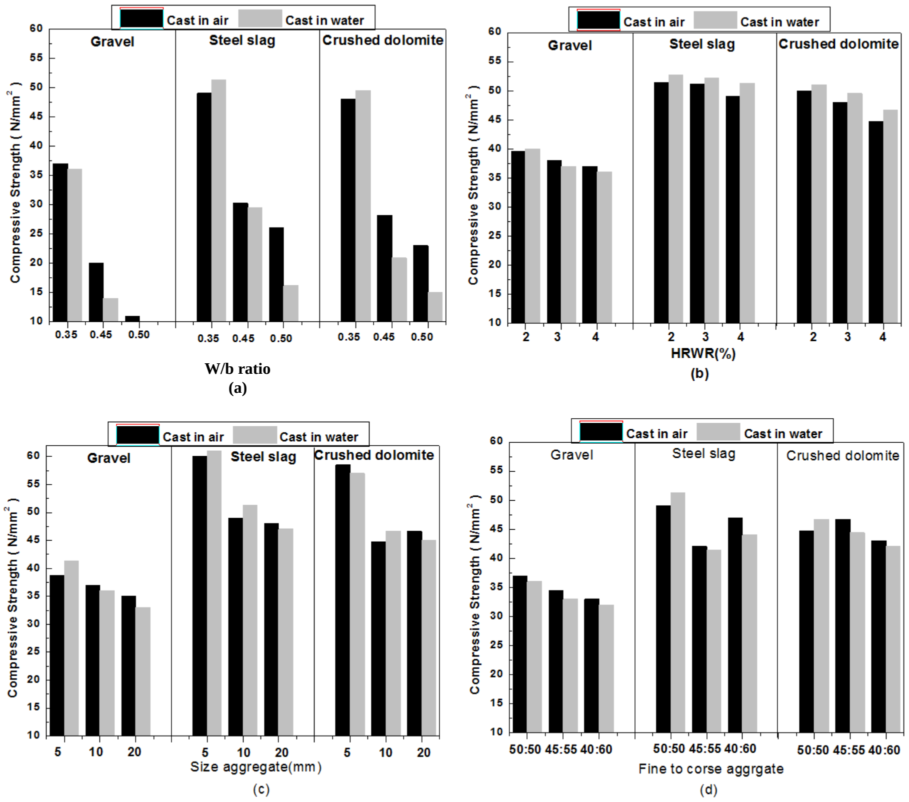
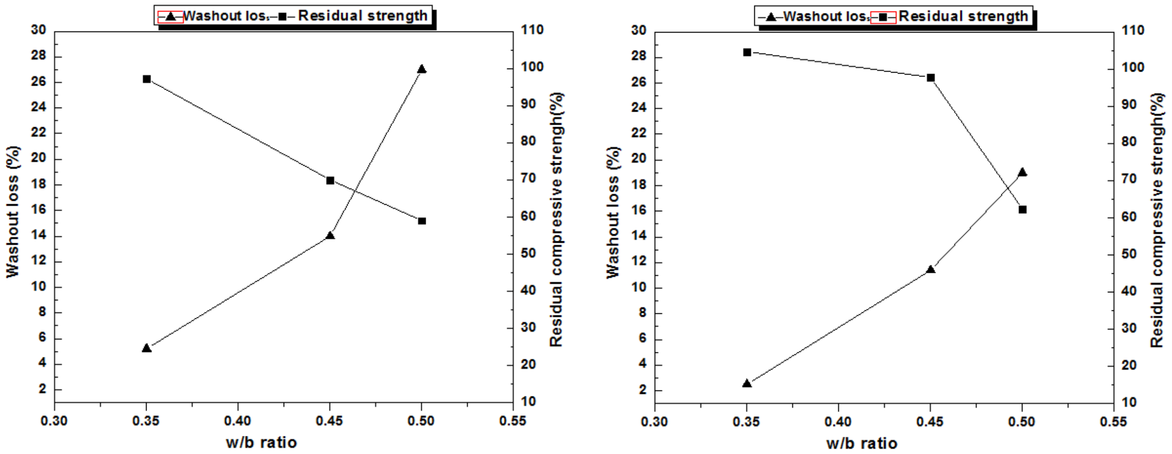


Figure 11: Compressive strength for all mixes at 28 days.

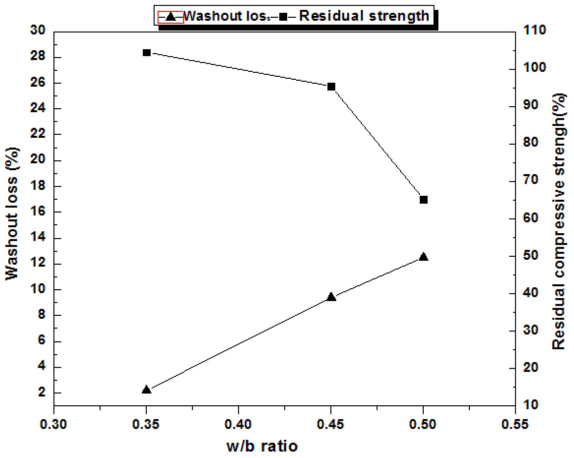
3.3. Relation between washout loss and residual strength

The increase in washout loss due to a higher w/b ratio was found to lead to a net decrease in residual compressive strength, from Figure 12, indicating that the strength of SCUWC is directly dependent on washout loss. For example, an increase in washout loss from 5.2 to 19% led to a reduction in residual strength from 97.2 to 59 for mixtures made with gravel. This can be attributed to the relative loss of cement paste associated with a potential infiltration of water inside the concrete which can both increase w/b and decrease compressive strength. This suggests that concrete parameters should be appropriately selected and proportioned to reduce washout loss and thereby maintain adequate residual compressive strength. This agrees with the study carried out by [9].



a -Gravel

b -Steel slag



C -Crushed dolomite

Figure 12: Washout loss and residual strength for mixtures made with various w/b ratio and various aggregates

4. Conclusions

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

1-The flowability of UWSCC decreases with the decrease in the maximum size of coarse aggregates and using steel slag aggregates with the same w/b ratio and superplasticizer dosage.

2- The gravel and crushed dolomite in the mixes gave higher slump, slump flow and T50 cm than steel slag in the mixes. This behavior attributed to the smooth texture of the surface of gravel and weight of steel slag aggregates to be more than that of gravel and crushed dolomite aggregates.

3- As a result of changing maximum size steel slag coarse aggregates from (5mm to 20mm), led to a decrease in (H_2/H_1) from (1 to 0.2%) respectively.

4- As a result of changing w/b ratio from 0.35 to 0.50, washout loss changed from 2.5 to 19% corresponding to a segregation from 12 to 35% respectively.

5- The unit weight of the underwater self-compacting concrete produced by steel slag ranges from 2500 to 2650 kg/m^3 which is higher by 13% compared to the unit weight of the conventional concrete.

6- After 28 days, the compressive strength of concrete specimens prepared with gravel, crushed dolomite and steel slag aggregates was 43.1, 57 and 61 N/mm^2 respectively.

7- Residual compressive strength of test specimens made underwater to those made in air decreased as w/b ratio increased. As a result of changing w/b ratio from 0.35 to 0.50 led to a decrease in compressive strength from 51.3 to 16.2 N/mm^2 for mixtures made with steel slag aggregates corresponding to a washout loss 2.5% - 19% respectively.

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