Performance Of Self Compacting Concrete Placed Underwater

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Abstract—The main objective of this study is to investigate the effect of anti washout admixture with various concentrations on fresh and hardened properties of self compacting concrete cast underwater. In this study, 16 mixtures was placed under water. The main parameters investigated in this study were: various concentrations of anti washout admixture, two dosages of superplasticizers, silica fume as replacement of cement content, limestone powder as replacement of cement content. The results obtained from this study indicates that the increasing AWA dosage from (0 to 1)%, for concrete mixes contain silica fume and limestone powder, reduced the slump flow by (25 - 33)% and (27-34)% respectively, decreases the standard washout mass loss by (69- 68)% and (75-78)% respectively, increased the compressive strength of concrete cast in standing water by (202 - 203)% and (266 -385)% respectively and increased the splitting tensile strength of concrete cast underwater by (169 - 191)% and (229 - 285)% respectively.

Index Terms— Antiwashout, compressive strength, splitting tensile strength, self compacting concrete, washout mass loss.

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1 INTRODUCTION

In recent years, as concrete structures in harbor, bridge, and marine constructions have become larger in wide range, the need for antiwashout underwater concretes has been increasing. Underwater concrete placement is used in the construction of new structures, such as in cofferdam bases and bridge foundations. As well as, it is often required for repair of marine structures and damaged hydraulic structures. Such repair can be carried out without dewatering to reduce the cost of repair resulting in considerable savings.

Underwater cast concrete must be proportioned to exhibit enough stability to reduce segregation and water dilution, and develop a homogeneous structure with adequate mechanical properties and durability. The concrete should spread from the discharge location under its own weight and form relatively flat repair surfaces. (1)

The antiwashout underwater concretes are produced by the addition of polymeric admixtures, namely Antiwashout Admixtures AWA. It increases the ability of the paste to retain part of the mix water leading to increase in the resistance to bleeding, segregation as well as water dilution. The use of AWA results in a high increased in yield value and some increase in viscosity. Additional high-range water reducer (HRWR) or superplasticizers (SP) is then added to secure the required level of deformability.(3, 4, 5)

Successful placement of concrete under water requires careful planning and attention to detail. The concrete must flow readily into place and consolidate under its own weight because vibration might cause contaminating water to mix with the casted concrete and wash out the cement and fine particles. Such washout can increase the turbidity and contamination of water and weaken strength, bond to reinforcement steel and durability (5,6).

Self compacting concrete (SCC) is a concrete which has the ability to flow by its own weight and achieve good compaction without external vibration. In addition, SCC has good resistance to segregation and bleeding because of its cohesive properties (7). So the objective of this study presented herein is to investigate performance of self compacting concrete placed under water used for hydraulic structure. Therefore, an attempt has been made to study the effect of the variations in the dosage of AWA and SP on washout mass loss, fresh properties and hardened properties of self compacting concrete placed underwater. Also, investigate the influence of use 20% limestone powder (LSP) as filler compared with use 10% silica fume (SF) as replacement of a portion of cement.

2 EXPERIMENTAL WORK

2.1 MATERIALS USED IN EXPERIMENTAL WORKS

Cement : sulfate resisting cement was used. Test results indicate that the adopted cement conforms to Iraqi specifications (IQS No.5/ 1984)(8). Its specific gravity is 2.96, and its fineness is 3100 cm2/gm. The cement content is represented by kg/m3.

Fine Aggregate : Natural sand from Al- Najaf region was used for concrete mixes of this investigation. Its specific gravity and the absorption of the fine aggregate are 2.56 and 1.5%, respectively, where fineness modulus is 2.12.

Coarse Aggregate : Natural irregular shap uncrushed coarse aggregate was used in this work with fineness modulus 6.05. The maximum aggregate size is 20 mm. The average specific gravity and the absorption of the coarse aggregate are 2.61 and 1%, respectively

Antiwashout admixtures (AWA) : (Flocrete) is a Brown powder antiwashout admixture for the underwater placement of concrete and grout.

Superplastisizer (SP) : Modified polycarboxylated ether based superplasticizer is a free flowing brown liquid of

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relative density 1.1+0.02 and its Chloride Content is nil. It is represented as a percentage of the cement content.

Silica fume (SF) : Silica fume is used as a cement addition. Its properties are conformed to ASTM Standard Specification Pozzolana and Admixture, and is represented by kg/m3.

Limestone Powder (LSP) : According to a ACI 237, the particle size less than 0.125 mm was used to increase the workability and density of the SCC. So the LSP sieve through a sieve No. 100 (125mm) and specific gravity is 2.25.

2.2 MIX PROPORTION

The proportion of concrete mixes are summarized in Table1. Enhancing flow characteristics in narrow area of the self consolidated AWA concrete by including high contents of cementitious material to limit aggregate volume. For all the mixes, the water to binder ratio was constant and other fresh properties were measured. The concrete was designed according to ACI 237 guidelines(9). Table 2 shows the details of the sixteen mixes used throughout this investigation.

TABLE 1 MIX PROPORTION OF INVESTIGATED CONCRETE

MATERIALS	10% SF	20% LSP
CEMENT (KG/M3)	427.5	380
SAND (KG/M3)	795	795
GRAVEL (KG/M3)	845	845
LSP (KG/M3)	—	95
SILICA FUME (KG/M3)	47.5	—
WATER (KG/M3)	214	214
W/CM	0.45	0.45
AWA%	0, 0.5, 0.75 and 1	0, 0.5, 0.75 and 1
SP %	1.75 and 3	1.75 and 3

TABLE 2 CONCRETE MIX DESIGNATIONS

MIX SYMBOL		SP (L PER 100 KG OF CEMENT)	AWA % (BY WT. OF CEMENT)
10% SF	20% LSP		
M1	M9	1.75	0
M2	M10		0.5
M3	M11		0.75
M4	M12		1
M5	M13	3	0
M6	M14		0.5
M7	M15		0.75
M8	M16		1

2.3 MIXING, CASTING AND CURING OF CONCRETE

All mixes were mixed in drum mixer. The mixing for the laboratory concrete consisted of homogenizing the sand and coarse aggregate, then introducing half of the mixing water followed by the cementitious materials. The remaining water, HRWR, and AWA were then introduced, and the concrete was mixed for 3 min. following 2 min of rest, the mixing was resumed for 2 additional minutes.

The placing process of the concrete mix is the most critical moment. All steel molds were prepared for mixing by placing oil along the interior surfaces of the mold in order to prevent adhesion with concrete after hardening. The underwater strength was determined by casting concrete into 150 x 150 mm cubes for compressive and 100 x 200 mm for tensile filled underwater without any consolidation. These results were compared to strengths determined on specimens cast in air. For the underwater casting, the molds were positioned in the container filled with water to a depth of 400 mm, the general cast method of antiwashout underwater concrete is depicted in Fig. 1. The specimens were left in the molds for 48 hrs then cured in water until the time of testing.

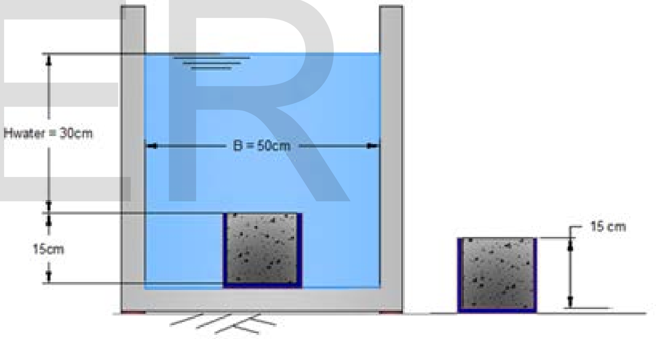

FIG. 1 CASTING METHOD OF ANTIWASHOUT UNDERWATER CONCRETE
(CASTING IN WATER AND CASTING IN AIR).

2.4 TEST METHOD

Testing of concrete in its fresh state is part of this study. The first performance attributes of SCC are filling ability, passing ability and stability. In this work many tests were used slump flow test, J-ring test, column segregation test and finally washout test. The test consists of determining the relative amount of cement paste lost of a fresh concrete sample after three drops through a determined column of water. The basket is dropped freely through a closed ended pipe filled with 1.7 m of clear water. After 15 sec at the bottom of the tube, the sample is retrieved in 5 sec and allowed to drain for 2 min before measuring its weight. The washout mass loss measured in flowing water can evaluated by filling a sample of 2,000 ± 20 g of fresh concrete into standard perforated basket used for the CRD C 61 test. The specimens were tested the compressive strength and The splitting tensile strength test. Each result of compressive strength obtained is the average for three specimens

3 ANALYSIS AND DISCUSSION OF THE RESULTS

3.1 SLUMP FLOW RESULTS

For non AWA concrete mixes contain silica fume, slump flow varied between 640-750 mm and 665-760 mm for mixes made with limestone powder. While for similar concrete mixes contain AWA, slump flow varied between 480-532.5 mm and 485-540 mm respectively.

As show in Table 3, slump flow decreased with increase of AWA dosage because of increasing the cohesion of the concrete in a way that significantly reduces the washout of the finer particles i.e. the cementitious material and sand from fresh concrete when it is placed underwater.

TABLE 3 RESULTS OF SLUMP FLOW TESTS

Mix Symbol	S. flow (mm)	T50 (sec)
M1	640	2
M2	505	28
M3	495	__
M4	480	__
M5	750	2.4
M6	532.5	41
M7	510	54
M8	500	64
M9	665	1
M10	515	32
M11	500	52
M12	485	__
M13	760	1.3
M14	540	29
M15	527.5	32
M16	500	50

The effect of variation of AWA and SP on slump flow is shown in Fig.2 . An increase in AWA from 0% to 1%, for a fixed dosage of SP, decreased the slump flow. For example, for concrete mixes contain silica fume and the dosage of SP 1.75 and 3 l /100 kg of cementitious material, the increasing AWA dosage from 0 to 1% reduced the slump flow by 25% and 33% respectively. In turn, for similar concrete mixes made with limestone powder, increasing AWA from 0 to 1% reduced the slump flow by 27% and 34% respectively.

T50 values increased with the increasing in dosage of AWA and decreased with the increasing in SP. For example, for concrete mixes contain silica fume, the T50 results varied between 2 to 64 sec. As well as, for concrete mixes made with limestone powder, the T50 results varied between 1 to 52 sec.

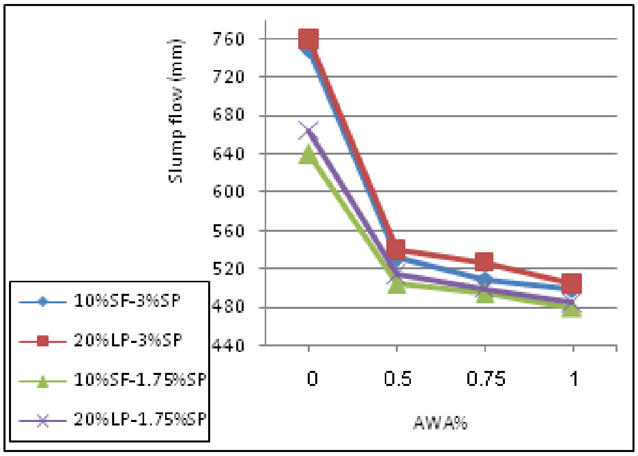

Fig. 2 Effect of AWA and SP on slump flow.

3.2 J-RING RESULTS

The effect of the variations of the dosage of AWA and SP on the J-ring tests are plotted in Fig 3. An increase of AWA dosage from 0% to 1%, decreased the J-ring. For example, for concrete mixes made with silica fume and 1.75 l / 100 kg of cementitious material, the increasing AWA concentration from 0% to 1.0% resulted in a reduction of j-ring values from 600 to 480mm, and from 630 to 480 for similar concrete mixes contain limestone powder. However, concrete mixes made with silica fume and 3 l / 100 kg SP, j-ring ranged from 700 to 495mm, and between 715 to 500mm for mixture with limestone powder.

TABLE 4 RESULTS OF J-RING TESTS

Mix Symbol	J-ring (mm)	Diff.
M1	600	40
M2	490	15
M3	485	10
M4	480	0
M5	700	50
M6	510	22.5
M7	500	10
M8	495	5
M9	630	35
M10	505	10
M11	495	5
M12	480	5
M13	715	45
M14	530	10
M15	520	7.5
M16	500	0

The differences between slump flow and J-ring values decreased with increase in AWA dosage, as shown in Fig 3. For example, for concretes made with 1.75 *l* / 100 kg dosage of SP for both replacement silica fume and limestone powder, increasing AWA concentration from 0 to 1% resulted in a reduction of the differences from (40 to 0), and (35 to 5) respectively. These value were (50 to 5), and (45 to 0) respectively, for similar concretes made with 3 *l* / 100 kg SP.

It is obviously that the increase in dosage of SP increased the J-ring. Reducing the dosage of AWA from 0.75% to 0.5% and increasing the dosage of SP from 1.75 *l* to 3 *l* (mix 3 vs. mix 6) increased the J-ring by 5.2%. The increase in AWA 0.75% to 1% and the reduction the dosage of SP from 3 to 1.75 *l* (mix7 vs. mix4) decreased the J-ring by 4%.

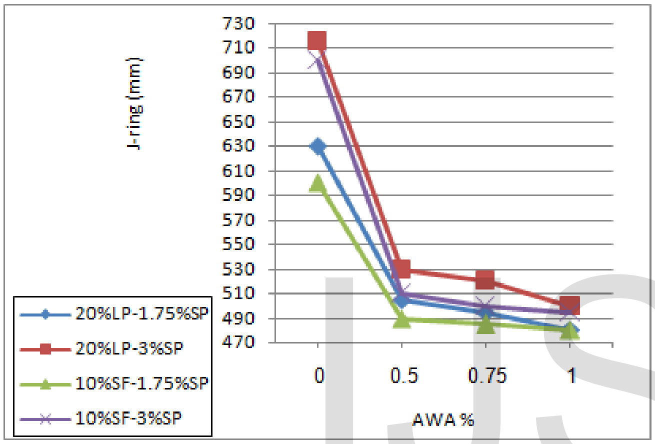

Fig.3 Effect of AWA and SP on J-ring test

3.3 COLUMN SEGREGATION RESULTS

Column segregation test evaluates the stability of the concrete mixture by quantify aggregate segregation when casting deep lifts using highly fluid concretes. S represented the values of segregation of concrete mixes. As shown in Table 5, result shows that incorporation of an AWA significantly reduces segregation. For concrete mixes made with 1.75 *l* for both replacement silica fume and limestone powder, the segregation resistance results varied between 7.9% and 0, and 12.4% to 0 respectively. As well as, for concretes made with 3 *l* SP for both replacement silica fume and limestone powder, the segregation resistance results varied between 8.2% and 0, and 13.2% to 0 respectively.

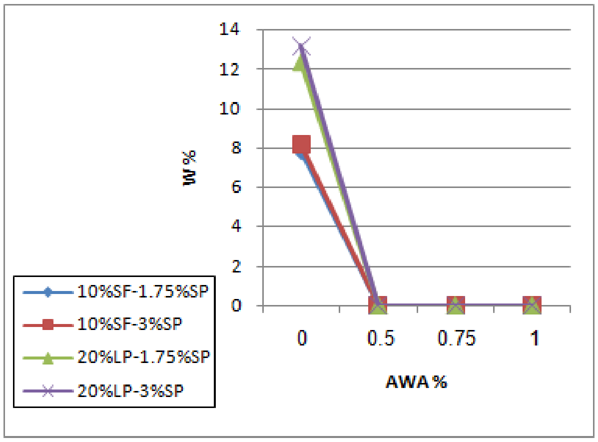

Fig. 4 Effect of AWA and SP on segregation resistance test.

TABLE 5 RESULTS OF COLUMN SEGREGATION AND WASHOUT MASS LOSS TESTS

Mix Symbol	S%	W%
M1	7.9	16.5
M2	0	7.2
M3	0	6.1
M4	0	5.1
M5	8.2	17.7
M6	0	7.9
M7	0	6.42
M8	0	5.6
M9	12.4	25.1
M10	0	8
M11	0	7.5
M12	0	6.3
M13	13.2	32.9
M14	0	8.97
M15	0	8.2
M16	0	7.4

3.4 WASHOUT MASS LOSS RESULTS

The washout test is used for determining the resistance of freshly mixed concrete to washing out in water. W represented the values of standard washout mass loss according to CRD C61 for AWA concrete, as shown in Table 5.

The non AWA concrete containing silica fume had a slump flow and a standard washout mass loss of 750 mm and 17.7% respectively. These value were 760mm and 32.9% respectively for similar concrete mixture made with limestone powder. The increase in slump flow consistency by adding SP resulted in higher washout loss, regardless of the dosage of AWA. This was especially the case for concrete with no AWA or with low AWA dosage. For a given AWA, additional HRWR can reduce yield value and affect the stability of the fresh concrete. This leads to the increase in free water content that reduces the ability of paste to retain water and suspended solid particles and fines (10).

The introduction of AWA , for the given dosage of SP, enhanced the washout resistance. It is clearly from Fig 5 and Fig 6 that increasing of AWA content resulted in a substantial reduction in loss of mass. For example, for concrete mixes made with silica fume and the dosage of SP 1.75 and 3 l / 100 kg, increasing AWA dosage from 0 % to 1%, decreases the loss of mass by washout by 69% and 68% respectively. These values were 75% and 78% respectively, for similar concrete mixes containing limestone powder. This illustrates the ability of the long chain AWA polymers to enhance the degree of water retention by adsorbing onto cement grains along with water, hence reducing washout loss (11)

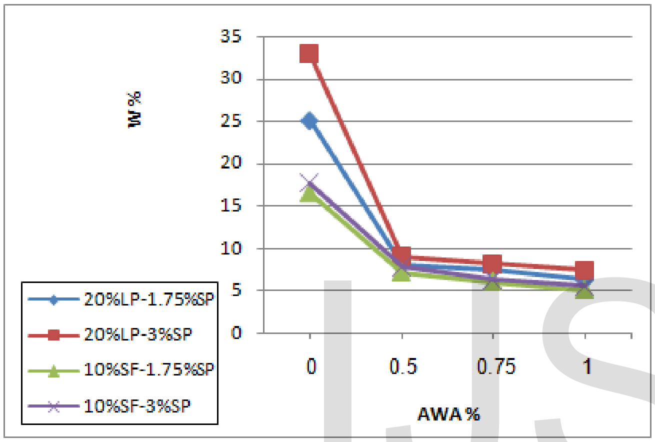

Fig. 5 Effect of AWA and SP on washout resistance.

a. without AWA b. with 1% AWA

Fig.6 Washout test with different dosage of AWA.

3.5 COMPRESSIVE STRENGTH RESULTS

The effect of AWA and SP on the fresh and hardened properties of SCC is studied. As reported earlier, the compressive strength of all the test specimens were determined from 150 mm cube specimens. The 28 days compressive strength determined for reference cube cast above water (fc air), for cube cast underwater (fc uw) and the relative compressive strength (fc uw/air) with various concentrations of AWA and two dosages of SP are presented in Table 6. It is important to note that the initial free fall of the concrete in standing water was approximately 0.3 m.

The effect of dosages of AWA and SP variations on the compressive strength of specimens cast underwater is illustrated in Fig 7. For example, for non AWA concrete containing silica fume the underwater compressive strength were 11.5-12.8 MPa and 6.2-9.1 MPa for concrete made with limestone powder. These value were 30.3-38.7 MPa and 26.7-33.3 MPa respectively for concrete mixture with AWA content.

As well as mixtures containing silica fume and the increased in AWA dosage from 0% to 1% and the dosage of SP 1.75 and 3 *l* /100kg, the compressive strength of concrete cast underwater was increased by 202% and 203% respectively. These value were 385% and 266% respectively for similar mixture made with limestone powder.

It is reasonable to attribute the drop in AWC strength to different mechanisms occurring during the casting stages. During the casting stage, the decrease in anti washout concrete strength may be related to washout loss and aggregate segregation which arise from a combination of factors such as agitation of concrete during placement and consolidation, turbulence of water, water velocity and the depth of casting location.(12)

TABLE 6 RESULTS OF COMPRESSIVE STRENGTH TESTS

Mix Symbol	fc air (MPa)	fc uw (MPa)	fc uw/ air (%)
M1	42	11.45	27
M2	41.7	30.32	73
M3	40.9	32.7	80
M4	40.5	34.6	85
M5	43.1	12.78	30
M6	41.9	33.17	79
M7	41.35	34.12	83
M8	41	38.7	94
M9	40.1	6.21	15
M10	39	26.7	68
M11	38.8	28.84	74
M12	38	30.11	79
M13	41.7	9.1	22
M14	39.56	27.91	71
M15	38.9	30.41	78
M16	38.5	33.28	86

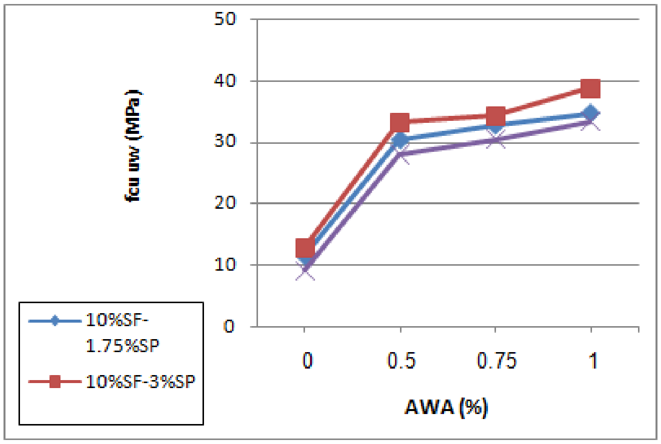

Fig 7 Effect of AWA and SP on compressive strength of concrete cast underwater.

The effect of AWA and SP with different content of AWA on the relative residual compressive strength is plotted in Fig 8. In general, the reduction of in place strength of concrete cast underwater compared to reference cylinder cast above water is due to water dilution of the cast concrete. Greater dosages of AWA resulted in reduction in washout loss for any given fluidity thus increasing the compressive strength. For example, for mixture containing silica fume and dosage of SP 1.75 and 3l/100kg of cementitious materials, the relative compressive strength was shown to increase from 27 to 85% and from 30 to 94% respectively with the increase in AWA dosage from 0 to 1%. These value were 15 to 79% and 22 to 86% respectively for limestone powder concrete mixture.

The relative compressive strength of 10% silica fume concrete containing 1% AWA developed the highest ratio of 94%. Such relative strength was 60% higher than those obtained without AWA. It is apparent that the more admixture the concrete contain, the greater ratio becomes. The concrete contain more than 0.75 % AWA, the relative compressive strength is greater than 70%.

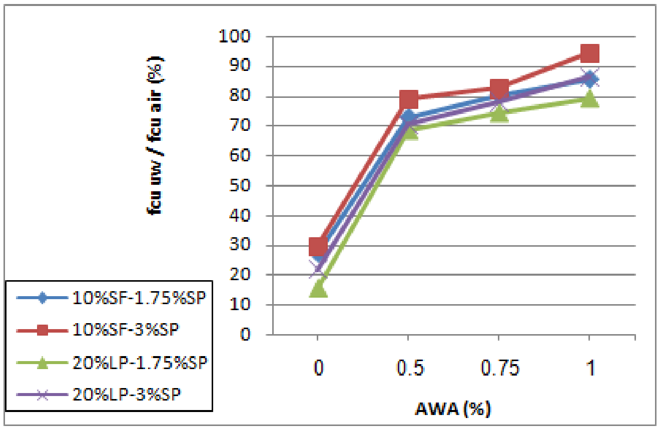

Fig 8 Effect of AWA and SP on relative compressive strength.

4.3.2.1 SPLITTING TENSILE STRENGTH RESULTS IN STANDING WATER

Several SCC placed underwater were investigated to study the effect of AWA and SP on the 28 days splitting tensile strength. Table 7 summarize the 28 days splitting tensile strengths, determined for reference cylinder cast above water (fs air), for cylinder cast underwater (fs uw) and the relative splitting tensile strength (f s uw /fs air) with different dosage of SP, various concentration of AWA and for both replacements silica fume and limestone powder.

The effect of the variations of dosages of AWA and SP on the splitting tensile strength of specimens cast underwater is illustrated in Fig 9. For example, for non AWA concrete containing silica fume and limestone powder the underwater splitting tensile strength were 1.08-1.21 MPa and 0.58-0.76 MPa respectively. These value were 2.68-3.52 MPa and 2.01-2.5 MPa respectively for similar concrete mixture with AWA content.

For a fixed dosage of SP, increasing AWA from 0 to 1% increased the splitting tensile strength of specimens cast underwater. For example, mixtures containing silica fume and the increase AWA dosage from 0 to 1.0% and the dosage of SP 1.75 and 3 l /100kg, the splitting tensile strength of concrete cast underwater was increased by 168.5% and 191% respectively. These value were 285% and 229% respectively for similar mixture made with limestone powder.

TABLE 7 RESULTS OF SPLITTING TENSILE STRENGTH TESTS

Mix Symbol	fs air (MPa)	fs uw (MPa)	fs uw / air (%)
M1	3.33	1.08	32
M2	3.245	2.68	83
M3	3.3	2.81	85
M4	3.24	2.9	90
M5	3.41	1.21	35
M6	3.5	3	86
M7	3.6	3.2	89
M8	3.82	3.52	92
M9	2.91	0.58	20
M10	2.79	2.01	72
M11	2.72	2.15	79
M12	2.73	2.23	82
M13	3.15	0.76	24
M14	3.1	2.4	77
M15	3	2.45	82
M16	2.89	2.5	87

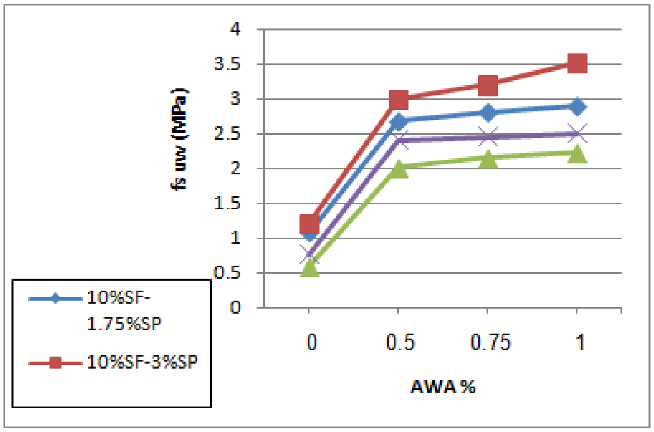

Fig 9 Effect of AWA and SP on splitting tensile strength of concrete cast underwater.

The effect of the variations of dosages of AWA and SP on the relative residual splitting tensile strength is plotted in Fig 10. For example, for mixture containing silica fume and dosage of SP 1.75 and 3 l /100 kg of cementitious materials, the relative splitting tensile strength was shown to increase from 32to 90% and from 35 to 92% respectively with the increase in AWA dosage from 0 to 1%. These value were 20 to 82% and 24 to 87% respectively for limestone powder concrete mixture.

The splitting tensile strength of 10% silica fume concrete containing 3 l /100 kg developed the highest ratio. It is apparent that the more admixture the concrete contain, the greater ratio becomes. For example, the concrete contain more than 0.75 % AWA, the relative compressive strength is greater than 80%.

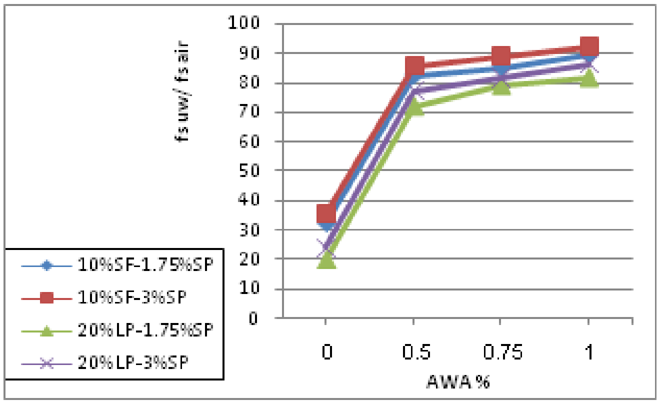

Fig 10 Effect of AWA and SP on relative splitting tensile strength.

4 CONCLUSIONS

From the experimental work of this research and the results obtained, the following conclusions are drown with the limitations of the study :

1. The increasing AWA dosage from 0 to 1%, for concrete mixes contain silica fume and limestone powder, reduced the slump flow by (25 - 33)% and (27-34)% respectively.
2. T50 values increased with the increasing in dosage of AWA and decreased with the increasing in SP. for concrete mixes contain silica fume, the T50 results varied between 2 to 64 sec. These value were 1 to 52 sec for concrete mixes made with limestone powder.
3. For non AWA concrete mixes contain silica fume and limestone powder, J-ring values varied between 600-700 mm and 630-715 mm respectively. While for similar concrete mixes contain AWA, J-ring values varied between 480-510 mm and 480-530 mm respectively.
4. Mixes made with limestone powder had higher slump flow and J-ring values by (3.9 - 0) % and (5 - 0) % respectively when increasing AWA from (0 to 1) % compared to similar mixes made with silica fume for any given dosage of SP.
5. When using AWA is used to reduce separation of concrete constituents is especially advantageous when casting deep lifts using highly fluid concretes. For non AWA concrete mixes contain silica fume and limestone powder, segregation resistance varied between 7.9-8.2% and 12.4-13.2 mm respectively. While segregation resistance was eliminated for similar concrete mixes contain AWA.
6. The washout resistance of underwater concrete can be significantly enhanced by increasing the AWA concentration despite the additional SP dosage necessary to maintain high consistency and self consolidated. Also for concrete mixes made with silica fume, increasing AWA dosage from 0 % to 1% decreases the standard washout mass loss by (69 – 68)% respectively. These values were (75 – 78)% respectively, for similar concrete mixes containing limestone powder.
7. Silica fume concrete with (0-1) % AWA dosage exhibit better standard washout resistance compared with similar concrete made with limestone powder by(46 - 24)% respectively .
8. The increasing AWA dosage from 0% to 1.0%, for mixtures containing silica fume, increased the compressive strength and splitting tensile strength of concrete cast in standing water by (202 – 203)% and (169 – 191)% respectively. These value were (266 – 385)% and (229 – 285)% respectively for similar mixture made with limestone powder.
9. The maximum relative compressive strength and maximum splitting tensile strength is 94% and 92% respectively for concrete with 10% silica fume containing 1% AWA .

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