Journal of Engineering Sciences, Assiut University, Vol. 40, No. 4, pp. 1005 -1023, July 2012

BEHAVIOUR OF UNDERWATER SELF COMPACTING CONCRETE

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(Received May 16, 2012 Accepted June 13, 2012)

Antiwashout underwater concrete AWA may be considered for use in a diverse range of work underwater, where its excellent characteristics are of great advantage.

Underwater concrete Anti-washout admixture (SIKAMENT 100 SC) is water soluble organic polymers, which increase the cohesion of the concrete in a way, that significantly reduces the washout of the finer particles, i.e. the cementinious material (cement and silica fume) and sand from fresh concrete when it is placed underwater. Researches for underwater concrete are commonly studied but the common mixes of SCC are rarely investigated underwater.

In this research, about 50 mixes of normal concrete NC and self compacting concrete SCC were prepared, in order to study the behaviour of under water SCC compared to NC using antiwashout admixtures (SEKAMENT 100 SC) Some parameters were studied such as AWA%, cement content, water cementitious ratio, coarse to fine aggregate ratio, and superplastisizer percent, in order to study the behavior of underwater SCC by measuring washout and out water/underwater minimum relative compressive strength to be added to the guidelines of underwater concrete applications.

Optimum values of some AWA components have been clarified; including cement content, water cementitious ratio, sand to aggregate ratio, and superplastisizer percentage.

KEYWORDS: *Antiwashout, compressive strength, self compacting concrete, underwater, washout*

1- INTRODUCTION

In recent years, as concrete structures in harbors, bridges, and marine constructions have become larger in the scale, the need for antiwashout underwater concretes to assure correct underwater placement has become greater. The major requirements for the antiwashout underwater concretes are antiwashout or segregation resistance, flowability, self-leveling ability, and bleeding control. The antiwashout underwater concretes are produced by the addition of antiwashout polymeric admixtures. Antiwashout underwater concrete may be considered for use in a diverse range of work underwater (fresh water or sea water), where its excellent characteristics (resistance to washout, filling property, and self-leveling ability) are of great advantage. Fig.(1) shows concrete placement by tremie method [1]

Antiwashout admixtures (AWAs) are among the agents recently used to minimize the adverse effects associated with underwater concrete placement. Antiwashout admixtures increase the cohesiveness of concrete to a level that allows limited exposure to water with little loss of cement. This allows placement of concrete in water and under water without the use of tremies.

The admixtures increase the viscosity of water in the mixture resulting in a mix with increased thixotropy and resistance to segregation. They usually consist of water soluble cellulose ether or acrylic polymers. The main objective of the admixture is to prevent wash-out of cement and dispersion of aggregate during underwater placement of concrete.

A water-soluble polymer acts as an antiwashout admixture in antiwashout underwater concrete. It is bonded to a part of mixing water by hydrogen bonds in the concrete, and disperses in a molecule form in the mixing water. As a result, the mixing water is confined in the network structure of the dispersed polymer, and becomes very viscous, and envelops cement and aggregate particles to impart an antiwashout character to the concrete [2]

Excellent guidance for design of abrasion-resistant underwater concrete has been previously provided [3].

In summary, successful placement of mass concrete under water imposes special demands on the properties of concrete, which include:

- Ability of concrete to flow around piles and reinforcing steel bars.
- Self-compacting, and sometimes self-leveling properties.
- Retention of workability over a reasonable work window of time.
- Adequate cohesion to avoid excessive segregation and laitance.
- Low heat of hydration.
- Low bleeding.
- Controlled set times.
- Development of adequate compressive strength and bond strength.
- Low creep and shrinkage.
- Resistance to cement dilution and washout by flowing water during concrete placement.
- Abrasion resistance, if exposed to flowing water.

According to the definition in ACI 116R [4], workability of concrete is “that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished”. In practice, the interpretation of concrete workability is inevitably project-specific. What represents workable concrete in one condition may become unworkable in another condition. Unless the level of concrete workability is specifically defined in the project specification and fully understood by all the parties involved in the design and construction, the project will face major risks of construction failure. In large-scale underwater concrete construction, workability of the concrete can be interpreted as being flowable, cohesive, and self-compacting within a specified period of time. In some projects, workability may also include additional requirements such as the ability of concrete to pass obstacles without segregation, self-leveling, and antiwashout characteristics. These fundamental characteristics of fresh concrete are most often evaluated on the basis of past experience, trial batching tests, and mock-up tests. The behavior of fresh concrete is closely linked to complex relationships among many concrete mixture variables, such as cement content and percentage of fines. Effects of one variable on the concrete workability are highly dependent on the other variables.

The relationships between the concrete workability and concrete mixture variables may be best explained with the theory of rheology.

Anti-washout admixture consists of long-chain saccharides polymers. When dissolved in water, the long-chain molecules form entanglement that partially restrains water mobility. Viscosity of the solution consequently increases. Upon agitation, the polymer chains tend to disentangle and align with the shear flow. Consequently, viscosity decreases with agitation intensity. The faster the shear flows, the lower the resistance to flow. When the agitation stops, the AWA polymer chains rapidly entangle again and the solution returns to its original viscosity. The thixotropic effects are pronounced in all AWA solutions. For the same reason, when added to concrete, AWA “thickens” the interstitial free water in concrete, making it more cohesive and thixotropic. AWA has been used as an antibleeding agent in posttensioning grout for many years. In the United States the use of AWA in underwater concrete was initiated by the Army Corps of Engineers for underwater repair of stilling basins [5].

Since then, AWA has been successfully used in numerous small to moderate-size projects. However, the U.S. experience of using AWA in large-scale projects is still limited.

In general, flowable and self-compacting concrete mixtures can be made without AWA. The necessity of using AWA stems from special performance requirements such as washout resistance and self-leveling characteristics. For reasons not yet fully understood, it seems that if AWA is fully hydrated it may not function properly in concrete unless high-range water reducers are also present. It is postulated that the cement particles need to be partially dispersed before AWA can form the necessary bridging between them. Therefore, it is preferable to add the AWA after the water-reducing admixture has been fully mixed with concrete.

Various test methods have been proposed to test the effectiveness of AWA. In Japan, for example, the PH level test method with a suction system has been standardized [6]. In North America, CRD-C61439A, titled “Test Method for Determining the Resistance of Freshly Mixed Concrete to Washing Out in Water,” has become the standard method. Past experience proved that CRD-C61-89A is a relatively simple and reliable way to measure the washout resistance. It also gives an indication of concrete resistance to segregation and laitance.

Liu [7] found that, use of AWA improves the bond strength between concrete and steel reinforcement, due to reduction of bleeding from the concrete mixture. In underwater construction of navigation structures, AWA is expected to improve the bond strength and hence the monolithic behavior between the precast concrete forms and tremie concrete due to reduction or elimination of bleeding and laitance.

It has also been experimentally found [8] that, certain types of AWA, such as welan gum, to a certain extent, stabilize the theological behavior of concrete with regard to variations of concrete temperature and the water content of aggregates. For example, the measured slump and viscosity of concrete containing welan gum was found to remain near constant even if the moisture content of aggregates was varied by plus or minus 1 percent. In practice, variations in quality and quantity of materials are inevitable in job site. Such variations often change the flowability, slump retention, and the time of set of concrete. The experimental results imply that, with proper use of AWA, more consistent performance of fresh concrete can be expected [8].

2- RESEARCH OBJECTIVES AND SCOPE

This paper investigates the behavior of underwater SCC using 50 different mixes.

- To optimize the SCC mixture proportions underwater, in order to realize the desired properties of underwater SCC weight loss, water cementitious and out water/underwater relative compressive strength.
- To study the influence of AWA%, cement content, water cementitious ratio, sand to aggregate ratio, and superplastisizer% on the underwater SCC, in order to obtain underwater SCC according to underwater guidelines.
- To compare between NC and SCC underwater.

3- EXPERIMENTAL PROGRAM

The behavior of SCC underwater specimens (M1 to M50 mixes) is studied. Table (1) shows the mix proportions of NC (M1 to M6), and of SCC (M7 to M42), as well as of SCC (M43 to M50) with a fixed percentage of AWA (1%), in order to study the effect of sand/aggregate ratio and superplastisizer. Table (2) shows the results of studied 50 mixes, including out water compressive strength (F_{ow}), underwater compressive strength (F_{uw}), relative compressive strength (F_{uw} / F_{ow}), underwater weight loss, pH value, and slump flow (SF)

3.1-Materials

Cement: Ordinary Portland cement grade 42.5 available in local market is used. It is tested for various proportions as per IS 4031-1988, and is found conformed to various specifications of are 12269-1987. Its specific gravity is 2.96, and its fineness is 3200 cm^2/gm. The cement content is represented by kg/m^3.

Coarse Aggregate (CA): Crushed stone from a local source is used as coarse aggregate with fineness modulus 6.05. The maximum aggregate size is 20 mm and the grading of coarse aggregates used corresponds to ASTM C33. The average specific gravity and the absorption of the coarse aggregate, determined according to ASTM C127, are 2.5 and 1.5%, respectively.

Fine Aggregate (FA): River sand is used as fine aggregate. Its specific gravity and the absorption of the fine aggregate are 2.6 and 0.57%, respectively, where fineness modulus is 2.77.

Antiwashout admixtures (AWA): (SEKAMENT 100 SC) is a Brown liquid and unique bipolymer anti-washout admixture for the underwater placement of concrete and grout.

Superplastisizer (SP): Modified polycarboxylated ether based superplasticizer is a free flowing brown liquid of relative density 1.08+0.01 and pH value 7+1, and its Chloride Content is nil (ASTM C494/C494M, Type F and ASTM C1017/C1017M). 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/m^3.

3.2-Mixing procedure

Mixing procedure takes place in three consequent steps:

1. Mixing dry constituents for 30 seconds

2. Adding water, superplastisizer and antiwashout admixtures at the same time.
3. Mixing the ingredients for another 90 seconds.

The total mixing time is 2 minutes.

In the laboratory, after initial two minutes of mixing, concrete is kept undistributed for seven more minutes and then is given one minute final mixing before starting flow tests for insuring superplastisizer activation.

Test method for determining the resistance of freshly-mixed concrete to washing out in water follows the US Army Corps of Engineers Standards: CRD-C 61-89A [9].

Apparatus:

<u>*Washout tube*</u>**:** It is a cylindrical clear plastic tube, Fig. (2). It's inside diameter is 190 ± 2 mm, it's outside diameter is 200 ± 2 mm, and it's height is 2,000 ± 2 mm.
<u>*Receiving Container*</u>: It is a cylindrical container with cover in the washout tube, Fig.(2). Both are made of perforated sheet steel with a nominal thickness of 1.4 mm. The perforations are circular with a nominal diameter of 3 mm. The distance between adjacent perforations is 5 mm. The container diameter is 130 ± 2 mm and its height is 120 ± 2 mm.
<u>*Rope*</u>: It is about 2500mm long rope, and is attached to the receiving container.
<u>*Rod*</u>: It is approximately a 300 mm straight steel rod, and 10-mm diameter. Its end is rounded to a hemispherical tip of the same diameter as the rod.
<u>*Scale*</u>: It is a scale, which allows the determination of the mass of the sample with a precision of 0.05 percent.

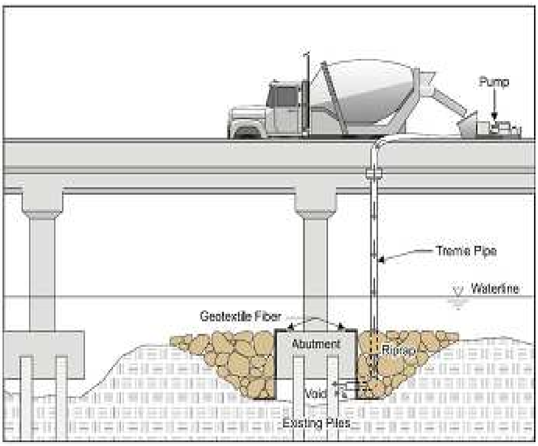


Fig.(1) Concrete placement by tremie method [1]

Fig. (2) Apparatus for washout test [9]

3.3-Procedure of washout test

- Level the washout tube base and fill the tube with water to a height of 1,700 ± 5 mm.
- Determine the mass of the receiving container and cover. Put slightly more than 2000g fresh concrete, into the receiving container.

- Rod the sample 10 times with a 10-mm diameter rod. Tap the side of the container with the rod 10 to 15 times. Clean the extruded concrete from outside the container 10 to 15 times. Record the mass of concrete as M_i, M_f.
- Attach the rope to the receiving container. Put the receiving container, while holding the sample with its cover in place into the washout tube, and lower until the bottom of the container is in contact with water.
- Let the receiving container fall freely through water to the bottom of the tube.
- After 15 sec, bring the receiving container up in 5 ± 1 sec. Let the receiving container drain for 2 min, then tilt slightly to allow water to run off the top of the sample. Determine the mass of concrete remaining in the receiving container and record as M_f. The loss in mass of the concrete in the receiving container is equal to M_i - M_f.
- Perform the sequence three times on the same sample, determining M_f each time. After the final sequence M_f is the cumulative loss in mass.

3.4-Calculations

Washout or loss of mass of the sample, expressed as percentage of its initial mass is given by Equation (1):

$$D = \frac{M_i - M_f}{M_i} \times 100 \qquad (1)$$

Where D = washout, %; M_i = initial mass of sample; M_f = mass of sample after each test.

4- RESULTS AND DISCUSSION

4.1- Washout of self compacting concrete

Underwater concrete antiwashout admixtures are water soluble organic polymers, which increase the cohesion of 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 under water. Antiwashout admixtures are often used in conjunction with superplasticiser, to produce flowing self-leveling concrete to aid placing and compaction under water. Anti-washout admixtures, combined with superplasticisers, require a long slow mixing action to achieve high workability.

4.1.1- Weight losses

Figure (3) represents the weight losses of fresh SCC concrete underwater. It indicates that, increasing AWA decreases the antiwishout, however with a diminishing rate for all cement contents. Antiwashout decreases, on the average, about 44% at 1% AWA. Further increase of AWA to 3% decreases antiwashout only about 33%. AWA overdose may be explained in view of entrained excessive air. On the other hand, the decrease of antiwashout with AWA is more pronounced at higher cement contents. It is shown also from the figure that, mixes of cement contents 450-500 kg/m^3 are accepted. Their weight losses are equal to or less than 8%. Mixes with cement contents less than

450 kglcm^3 need over 1%AWA to be accepted. Mixes containing 350, 300,250, or 200 kg/m^3 cement, need 1.5, 1.5, 2 or 3% AWA to be accepted, respectively.

It is worth noting that, a minimum cement of 450 kg/m^3 is needed, if no AWA is applied, whereas, the minimum cement content for mixes with 1%AWA is 300-350 kg/m^3 to achieve the washout requirements.

4.1.2- Effect of pH

The turbidity of water due to washout results in more alkalinity. After washout tests, the pH value was recorded as a second indicator for washout. Fig.(4) indicates that, the pH value decreases with increasing AWA for all cement contents. The rate of washout resistance decreases with pH value for all specimens, and the rate of washout resistance is high for AWA up to 1%. The rate of washout resistance decreases over 1% AWA. It is clear, that the cement content is more effective for rich cement content up to 1% AWA where it is more effective for poor cement content over 1% AWA. This agrees with the above results of weight losses for pH =12.5, which gives the guideline of pH for antiwashout.

The minimum requirements of the cement content to achieve pH values are similar to the cement contents to achieve weight loss requirements.

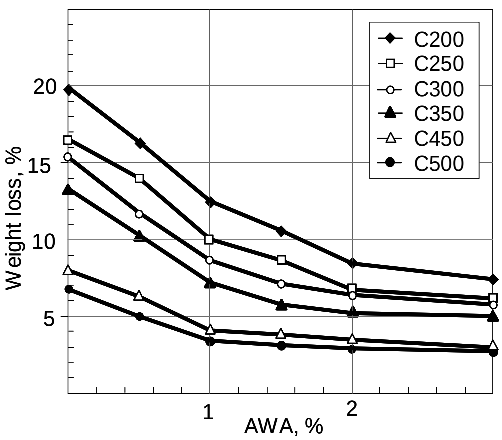


Fig.(3) Effect of AWA on weight loss

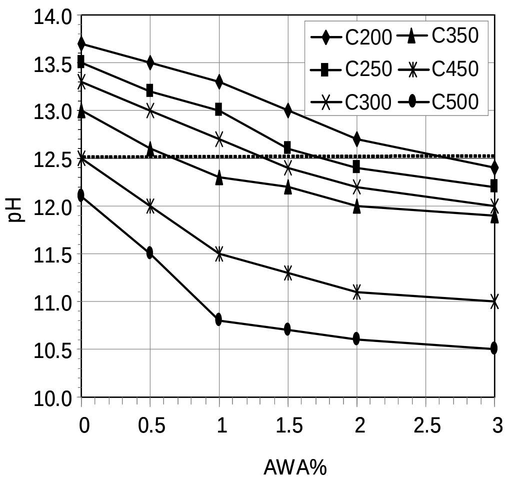


Fig.(4) Effect of AWA pH

4.1.3- Relation between WL and Ph

The guide line of the washout commonly represented by the weight loss and the pH values is recorded for all mixes underwater, in order to obtain the pH value related to the weight losses. Thus, it is strongly recommended to put a guide line for maximum pH value. The relation between the pH value and the weight losses is indicated in Fig. (5). It is obvious, that a value of about 8% weight losses corresponds to a pH value of 12.5. It is to be noted, that based upon the allowable value of washout, the pH values of mixes without AWA are higher than those containing AWA. On the other hand, pH values corresponding to weight losses over 8% for all mixes without AWA are less than those of mixes, which contain AWA. Moreover, results show that the effect of

AWA is more effective when washout is over 8%. Plate (1) shows pH measuring where plate (2) shows the technique of casting underwater.

Plate (1) pH value measuring

Plate (2) Casting underwater

Equations (2) and (3) represent the pH values (y) related to the weight losses (x) for all mixes without and with AWA, respectively.

$$y = 0.1195x + 11.427 \quad (2)$$

$$y = 0.2645x + 10.247 \quad (3)$$

4.1.4- Effect of w/c on washout

Figure (6) indicates the effect of water cementitious ratio on weight losses. The resistance to washout decreases with w/c for both mixes. The viscosity of Antiwashout underwater concrete increases with the quantity of antiwashout admixture used. Hence, the unit water content necessary to obtain the required fluidity, also, increases. A superplastisizer is added to counteract this effect. Although the amount of high-range water-reducing agent is correctly determined according to the quantity of antiwashout admixture, it is preferable to add excessive quantities, as long as no ill-effects such as loss of antiwashout properties or delayed setting take place. Besides, it is obvious that using AWA, the rate of resistance of antiwashout is high compared to mixes without AWA. This may be due to the high viscosity of mixes containing AWA.

Equations (4) and (5) give the relations between the water cementitious ratio (x) and weight losses (y) for mixes without AWA and with AWA, respectively.

$$y = 92.484x - 26.307 \quad (4)$$

$$y = 74.299x - 20.229 \quad (5)$$

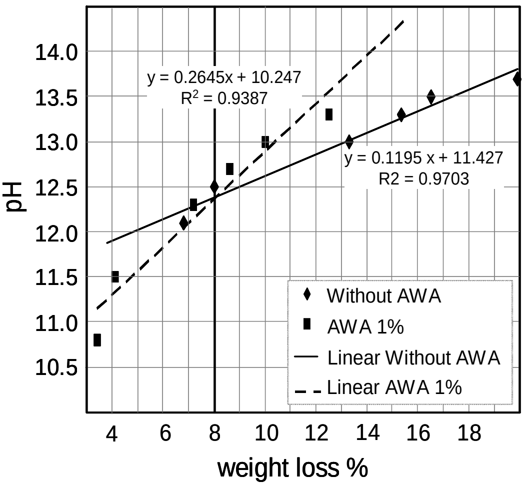


Fig. (5) Value of pH vs. Weight loss

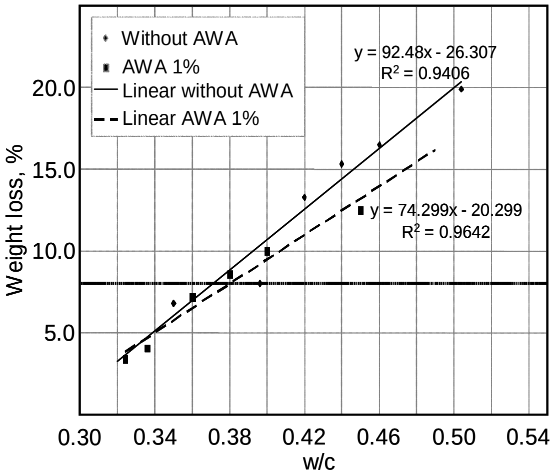


Fig. (6) Weight loss vs. water cementitous ratio.

4.1.5- Washout of SCC and NC

It is very important to compare the antiwashout between NC and SCC. Thus, Figs. (7) and (8) show a comparison of washout between both NC and SCC, where both figures represent the weight loss and pH values of mixes containing 1%AWA for both NC and SCC, that give good results of compressive strength for most mixes, as shown in the next section.

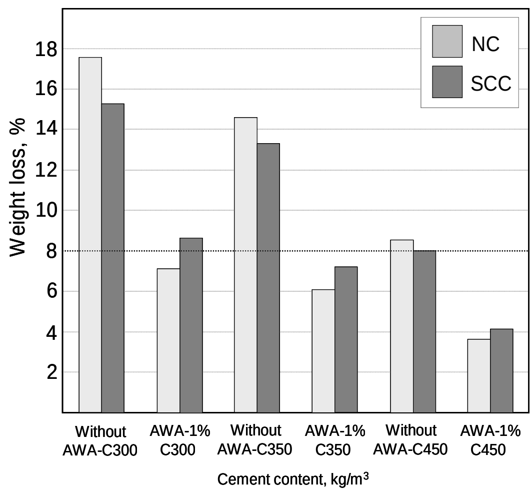


Fig. (7) Weight losses for NC and SCC

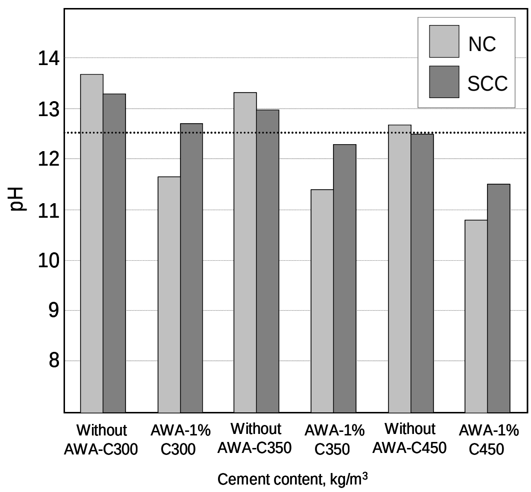


Fig. (8) Values of pH for NC and SCC

For all mixes (NC and SCC) without AWA, washout is accepted over 450 kg/m^3 cement content. Antiwashout for SCC is more efficient than NC, due to the effect of silica fume and the little water cementitious ratio with superplastisizers, which enhance washout. The washout of SCC is enhanced by about 10% over that of NC, and the enhancement is more effective for cement rich mixes. For all mixes with AWA, almost all mixes are accepted, and the efficient antiwashout of NC is higher than SCC by about 15%, especially for rich cement content. This may be due to, the effect of AWA which may increase the fluidity of SCC mixes in the presence of superplastisizer.

4.2 Compressive strength of Underwater SCC

4.2.1-Effect of antiwashout admixture

The effect of AWA on the compressive strength is illustrated in Fig. (9), which indicates that, the optimum value of AWA is 1%, which gives maximum compressive strength for cement contents in the range 350-500 kg/m^3, whereas the optimum AWA value is 1.5% for cement contents in the range 200-300 kg/m^3.

AWA is water soluble organic polymer, which increases the cohesion of 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. It is also used in conjunction with superplasticisers to produce flowing self-leveling concrete, to aid placing and compaction underwater, hence, improving the integrity of concrete placed underwater and reducing the impact, that the washed out cementitious material can have in marine environment. AWA enhances underwater compressive strength. The optimum dose of poor cement mixes is 1.5%, while that of rich cement mixes is 1%, to achieve optimum compressive strength.

Overdosing of the anti-washout admixture may result in an increase in air-entrainment, which tends to lower the compressive strength. Cohesion and anti-washout properties are increased, which may lead to reduced concrete workability. Besides, the set time may be increased.

4.2.2-comparison between underwater and out water compressive strength of SCC

It is shown from Fig. (10), that the relative under to out water compressive strength increases with cement content either with or without AWA. Also, AWA enhances the relative underwater to out water compressive strength. The enhancement is very effective for cement contents over 300 kg/m^3.

The required underwater to out water compressive strength should be greater than 70%, as indicated earlier. The required cement for underwater mixes without AWA should be more than 390 kg/m^3, while the required cement content using AWA is 295 kg/m^3.

However, minimum cement content requirement to achieve antiwashout was (450 kg/m3) without AWA and (300-350 kg/m3) for AWA. So, it is recommended to use the requirements of cement content for washout which cover the requirements of relative compressive strength.

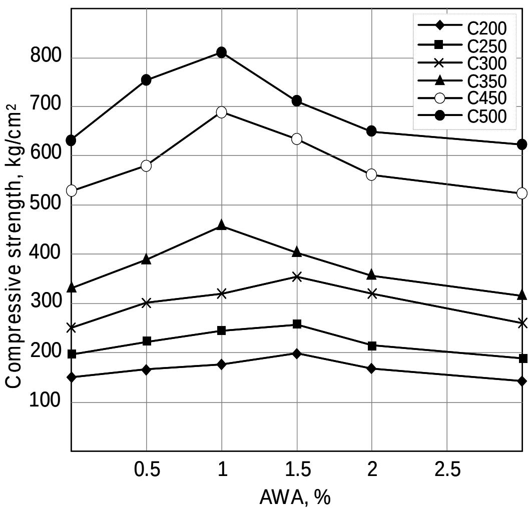


Fig. (9) Effect of AWA% on underwater SCC

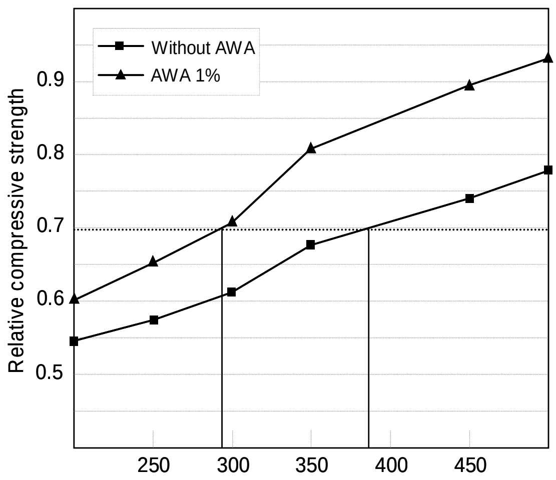


Fig. (10) Effect of cement content on Underwater/out water compressive strength

4.2.3- effect of cement content of SCC on underwater and out water compressive strengths

Results of Fig.(11) show that about 20 mixes of 36 achieve the requirements of underwater to out water compressive strength, especially for cement contents over 300 kg/m^3. The maximum relative compressive strength is 93% using 1%AWA and 500 kg/m^3 cement content. It is obvious that, all AWA percentages with cement content over 300 kg/m^3 achieve the relative compressive strength, whereas mixes without AWA achieve the relative compressive strength at 350-450 kg/m^3 cement content.

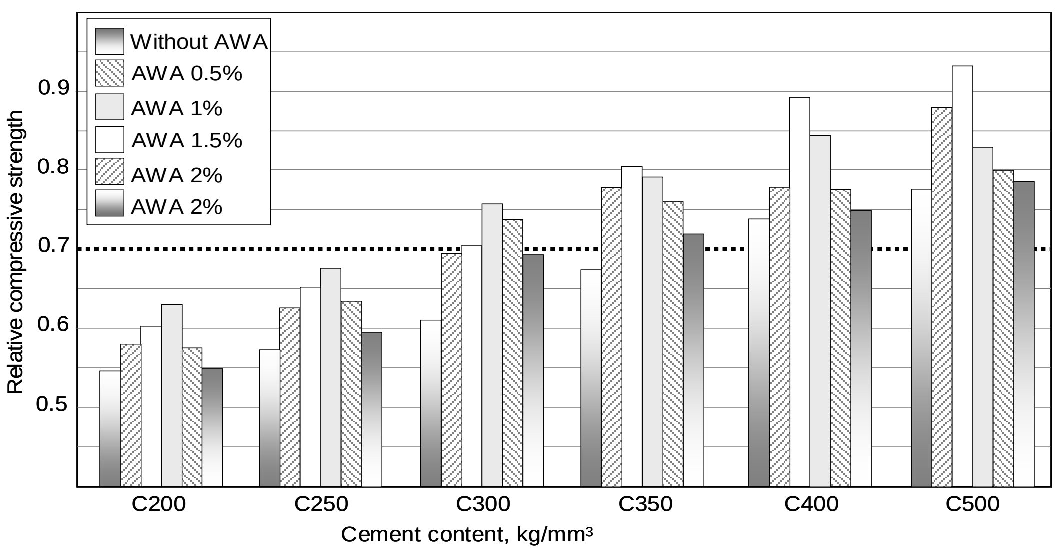


Fig. (11) Relative out water/underwater compressive strength

4.2.4 Comparison between underwater compressive strength of NC and SCC

The ratio of underwater to out water relative compressive strengths for 1% AWA is indicated in Fig. (12). It is observed that, the performance of SCC is of a higher efficiency than that of NC, whether using AWA or not. The relative compressive strength of SCC is 7% higher than that of NC. On the other hand, using 1%AWA increases the relative compressive strength of SCC by about 12% than NC.

The results of antiwashout in Fig.(7), indicate that, the performance of NC is of a higher efficiency than SCC without AWA. Thus, the increment of relative compressive strength of SCC over that of NC is low where it was relatively high with AWA that is because of high antiwashout of SCC with AWA.

4.2.5-Effect of water cementitious ratio on SCC relative compressive strength

It is sown from Fig. (13) That water cementitious ratio (x) has an effect of relative compressive strength (y) of underwater SCC without AWA and with 1%AWA. The relative compressive strengths were obviously decreased with increasing water cementitious ratio for both SCC mixes either without or with AWA which represented with a straight lines ad indicated in Equations (6) and (7).

$$y = 1.9566e\text{-}2.5781x \qquad \text{without AWA} \tag{6}$$

$$y = 3.0245e\text{-}3.694x \qquad \text{with AWA} \tag{7}$$

In the case of antiwashout underwater SCC, a rule for the water-cement ratio can be expressed and there is a straight-line relationship between compressive strength of specimens prepared underwater and the water cementitious ratio, as in the case of ordinary concrete.

The rate of degradation of relative compressive strengths of mixes with AWA was more than mixes without AWA. This results may due to the effect of reducing superplastisizer and water cementitious ratios for mixes with AWA to obtain more cohesive SCC mixes which increase the values of out water compressive strength hence the relative compressive strengths were more decreased. However, less than about 0.4 water cementitious ratios, the relative compressive strengths of SCC with 1%AWA were more than SCC mixes without AWA that is because of high performance of antiwashout of mixes with less water cementitious ratios. With increasing water cementitous ratios over 0.4 for SCC containing 1% AWA, the performance of antiwashout decreases and cohesion may be decreased hence the relative compressive strengths were less than SCC mixes without AWA.

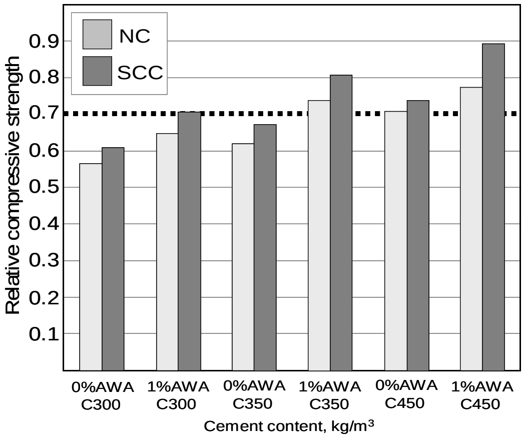


Fig. (12) Relative out water/underwater compressive strength

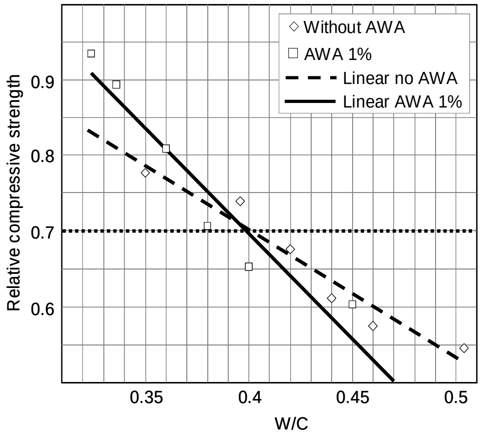


Fig. (13) Relation between W/C and underwater/out water compressive strength

4.3 Effect of fine AWA on slump flow

Slump flow of SCC was recorded for all mixes in order to study the effect of AWA and cement ratio on the slump flow in order to maintain the flow ability of SCC.

Figure (14) illustrated the effect of AWA on the slump flow. The slump flow suitable for the operation may differ according to the construction site, the construction conditions, the reinforcing bar arrangement, the placing method, etc. Although work is easy using soft concrete with larger slump flow, such concrete tends to contaminate the water and result in sinking of the coarse aggregate during placing. On the other hand, harder concrete with a smaller slump flow does not flow well in water even though its antiwashout properties underwater are improved. This may result in structural defects, such as insufficiently filled portions, depending on the shape and reinforcing bar arrangement. For these reasons, the slump flow should be carefully chosen within the range suitable for the work with reference also to the required antiwashout properties, filling properties, and self-leveling properties of the concrete.

The standard range of slump flow for antiwashout under water concrete for concrete placed into complex shape high fluidity is required (500-600 mm) that may achieved by using SCC.

Figure showed that slump flow decreased with AWA that is 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. The rate slump flow reduction was steeper up to 2%AWA. Over than 2%AWA the reduction of slum flow was less steeper that is because of reducing superplastisizer for underwater SCC with 1% AWA.

Results of Fig. (15) Represented the effect of cement content on the slump flow in the presence of AWA. For cement content less than 350 kg/m3, slump flow slightly decreased for all AWA percentages because of the effect of AWA that increase the viscosity of underwater SCC mixes. For high cement content over 350 kg/m3, slump slow was obviously increased that is May because of high quantity of superplastisizer in rich mixes that may interact with AWA and gave a negative effect on the viscosity hence increasing slump flow.

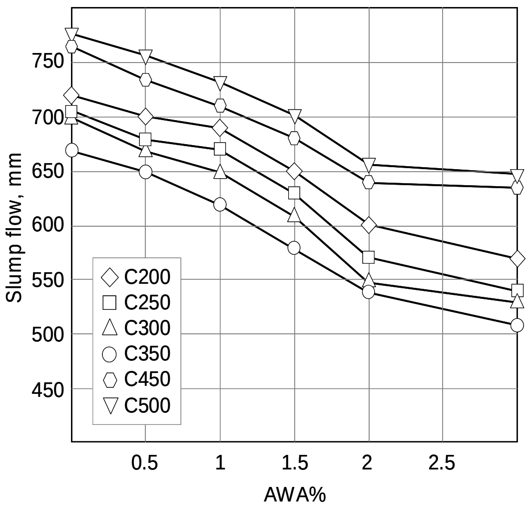


Fig. (14) Effect of AWA on slump flow

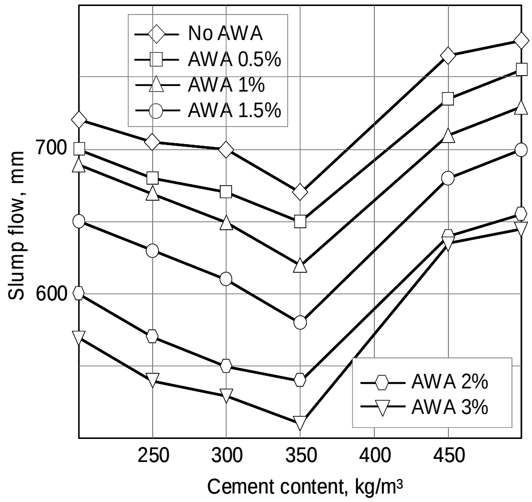


Fig. (15) Effect of cement content on slump flow.

4.4 Effect of sand aggregate ratio

Figure (16) represented the effect of sand aggregate ratio on the relative compressive strengths for underwater SCC. It is shown from figure that the optimum content of sand aggregate ratio of SCC mixes underwater without AWA was 0.5 where the optimum ratio was 0.4 for mixes with AWA. In the case of antiwashout underwater concrete, the concrete resists washout even with less sand due to the effects of the antiwashout admixture. It is illustrated from the figure the high effect of AWA on the relative compressive strength

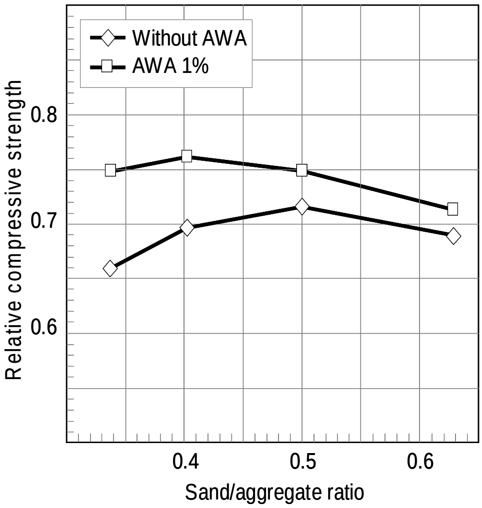
4.5 Effect of superplastisizer

The effect of superplastisizer on the washout was illustrated in Fig. (17), the effect of superplastisizer was obviously increased antiwashout for both mixes with and without AWA up to 3% superplastisizer. Over than 3%, antiwashout decreased for both mixes. On the other hands, antiwashout rate of mixes with AWA was better than mixes without AWA with a high rate of antiwashout however more than 3% superplastisizers both mixes begin weak for antiwashout but mixes without AWA was less resistance than mixes with AWA up to about 4.5% superplastisizer. Over than 4.5% superplastisizer, antiwashout of SCC without AWA was more performance to antiwashout that SCC mixes with AWA. The optimum relative compressive strengths were at 3% superplastisizers which insure the results of washout. It is known that there are some problems between high-range water-reducing agents and antiwashout admixtures, and there have been cases where unfavorable symptoms appear, such as an increase in air content, a resulting loss of strength, and reduction in fluidity, depending on the combination. Consequently, it is essential to confirm that the high-range water-reducing agent used in combination with the antiwashout admixture is not harmful to the concrete. That may be achieved when using superplastisizer up to 4.5%. the harmful of antiwashout for SCC mixes without AWA does not appear so the reduction of antiwashout was less over 3% superplastisizers.

Equations (8) and (9) represented the relations between weight loss % (y) and superplastisizer % (x) without and with AWA respectively

$y = 0.757x2 - 4.3474x + 11.503$ without AWA (8)

$y = 1.1815x2 - 6.4957x + 12.71$ with AWA (9)



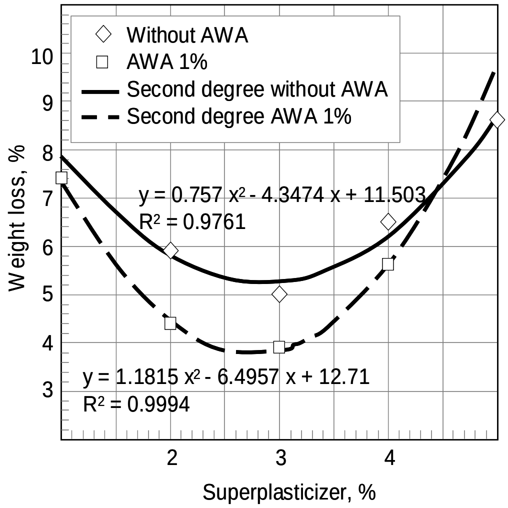


Fig. (16) Effect of sand/aggregate ratio on underwater /out water compressive strength.

Fig. (17) Relation between superplasticizer% on underwater/out water compressive strength

5-CONCLUSION

AWA has been shown to exhibit adequate antiwashout properties when tested according to CRD-C 661-06. However, since antiwashout performance is very dependent on mix proportions, cement content, w/c ratio, slump flow, and superplastisizer, potential mix designs for a specific project should be tested, with actual job materials, to ensure that the antiwashout performance of the chosen concrete design will meet the actual project specification. The following recommendations and outlines of underwater SCC was represented in this study as:

1) Antiwashout of SCC can be improved by about 44% for different cement content where as relative underwater/out water compressive strength can be improved up to 0.93
2) Optimum AWA percentage was 1% for high level of cement and 1.5% for low level of cement
3) The guideline of pH value which meets 8% weight loss was 12.5 that can indicated the washout
4) The performance of SCC for antiwashout was more than NCC if AWA was used however the performance of NC was better without AWA
5) Minimum cement content for underwater SCC for optimum AWA was about 300 kg/m3 in order to achieve the guidelines of out water/underwater

compressive strength (0.7) and antiwashout where the content was (400-450) kg/m3 for under water SCC mixes without AWA.

6) the relative out water/underwater compressive strengths of SCC was more than NC
7) It is recommended that water cementitious ratio of underwater SCC not exceeds than 0.4 in order to achieve the guidelines of underwater.
8) slump flow was decreased by using AWA specially for high cement content

Table (1) mix proportions

Mix	cement	SF	CA	FA	SP	w/c	AWA%
M1-NC-AWA 0%	300	0	1340	670	0	0.50	0
M2-NC-AWA 1%	300	45	1340	670	3	0.43	1
M3-NC-AWA 0%	350	0	1340	670	0	0.50	0
M4-NC-AWA 1%	350	45	1340	670	3	0.38	1
M5-NC-AWA 0%	450	0	1340	670	0	0.50	0
M6-NC-AWA 1%	450	45	1340	670	3	0.30	1
M7-SCC-AWA 0%	200	225	961	743	5	0.50	0
M8-SCC-AWA 0.5%	200	225	961	743	4.5	0.48	0.5
M9-SCC-AWA 1%	200	225	961	743	4	0.45	1
M10-SCC-AWA1.5%	200	225	961	743	3.5	0.42	1.5
M11-SCC-AWA 2%	200	225	961	743	3	0.40	2
M12-SCC-AWA 3%	200	225	961	743	2	0.38	3
M13-SCC-AWA 0%	250	220	961	731	5	0.46	0
M14-SCC-AWA 0.5%	250	220	961	731	4.5	0.42	0.5
M15-SCC-AWA 1%	250	220	961	731	4	0.40	1
M16-SCC-AWA1.5%	250	220	961	731	3.5	0.38	1.5
M17-SCC-AWA 2%	250	220	945	731	3	0.36	2
M18-SCC-AWA 3%	250	220	945	731	2	0.36	3
M19-SCC-AWA 0%	300	21`0	928	718	5	0.44	0
M20-SCC-AWA 0.5%	300	210	928	718	4.5	0.40	0.5
M21-SCC-AWA 1%	300	210	928	718	4	0.38	1
M22-SCC-AWA1.5%	300	210	928	718	3.5	0.36	1.5
M23-SCC-AWA 2%	300	210	928	718	3	0.33	2
M24-SCC-AWA 3%	300	210	928	718	2	0.34	3
M25-SCC-AWA 0%	350	205	912	706	5	0.42	0
M26-SCC-AWA 0.5%	350	205	912	706	4.5	0.38	0.5
M27-SCC-AWA 1%	350	205	912	706	4	0.36	1
M28-SCC-AWA1.5%	350	205	912	706	3.5	0.34	1.5
M29-SCC-AWA 2%	350	205	912	706	3	0.32	2
M30-SCC-AWA 3%	350	205	912	706	2	0.30	3
M31-SCC-AWA 0%	450	225	700	888	5	0.40	0
M32-SCC-AWA 0.5%	450	225	700	888	4.5	0.36	0.5
M33-SCC-AWA 1%	450	225	700	888	4	0.34	1
M34-SCC-AWA1.5%	450	225	700	888	3.5	0.32	1.5
M35-SCC-AWA 2%	450	225	700	888	3	0.30	2

M36-SCC-AWA 3%	450	225	700	888	2	0.28	3
M37-SCC-AWA 0%	500	215	760	850	5	0.35	0
M38-SCC-AWA 0.5%	500	215	760	850	4.5	0.34	0.5
M39-SCC-AWA 1%	500	215	760	850	4	0.32	1
M40-SCC-AWA1.5%	500	215	760	850	3.5	0.30	1.5
M41-SCC-AWA 2%	500	215	760	850	3	0.28	2
M42-SCC-AWA 3%	500	215	760	850	2	0.25	3
M43-SCC-AWA 0%	215	230	1180	600	5	0.36	0
M44-SCC-AWA 1%	215	230	1180	600	4	0.32	1
M45-SCC-AWA 0%	215	230	980	660	4	0.4	0
M46-SCC-AWA1%	215	230	980	660	3	0.36	1
M17-SCC-AWA 0%	215	230	890	890	3	0.44	0
M48-SCC-AWA 1%	215	230	890	890		0.38	1
M49-SCC-AWA 0%	215	214	680	1150	2	0.47	0
M50-SCC-AWA 1%	215	214	680	1150	1	0.43	1

Table (2) results of washout and compressive strength

Mix	**F_{ow}**	**F_{uw}**	**F_{uw}/F_{ow}**	**weight loss%**	**pH**	**SF**
M1-NC-AWA 0%	310	175	0.565	17.6	13.7	450
M2-NC-AWA 1%	340	221	0.650	7.1	11.7	400
M3-NC-AWA 0%	365	227	0.622	14.6	13.3	480
M4-NC-AWA 1%	420	310	0.738	6.1	11.4	420
M5-NC-AWA 0%	470	334	0.711	8.5	12.7	530
M6-NC-AWA 1%	488	378	0.775	3.6	10.8	450
M7-SCC-AWA 0%	275	150	0.545	19.9	13.7	720
M8-SCC-AWA 0.5%	286	166	0.580	16.3	13.5	700
M9-SCC-AWA 1%	295	178	0.603	12.5	13.3	690
M10-SCC-AWA1.5%	313	198	0.633	10.5	13.0	650
M11-SCC-AWA 2%	290	167	0.576	8.4	12.7	600
M12-SCC-AWA 3%	259	142	0.548	7.4	12.4	570
M13-SCC-AWA 0%	343	197	0.574	16.5	13.5	705
M14-SCC-AWA 0.5%	356	223	0.626	14.0	13.2	680
M15-SCC-AWA 1%	375	245	0.653	10.0	13.0	670
M16-SCC-AWA1.5%	382	259	0.678	8.6	12.6	630
M17-SCC-AWA 2%	333	212	0.637	6.7	12.4	570
M18-SCC-AWA 3%	312	186	0.596	6.1	12.2	540
M19-SCC-AWA 0%	412	252	0.612	15.3	13.3	700
M20-SCC-AWA 0.5%	432	300	0.694	11.7	13.0	670
M21-SCC-AWA 1%	453	320	0.706	8.6	12.7	650
M22-SCC-AWA1.5%	465	353	0.759	7.1	12.4	610
M23-SCC-AWA 2%	434	321	0.740	6.3	12.2	550
M24-SCC-AWA 3%	375	260	0.693	5.7	12.0	530
M25-SCC-AWA 0%	493	333	0.675	13.3	13.0	670
M26-SCC-AWA 0.5%	500	390	0.780	10.3	12.6	650
M27-SCC-AWA 1%	570	461	0.809	7.2	12.3	620

M28-SCC-AWA1.5%	511	405	0.793	5.7	12.2	580
M29-SCC-AWA 2%	470	358	0.762	5.2	12.0	540
M30-SCC-AWA 3%	444	320	0.721	5.0	11.9	510
M31-SCC-AWA 0%	717	530	0.739	8.0	12.5	765
M32-SCC-AWA 0.5%	745	580	0.779	6.3	12.0	735
M33-SCC-AWA 1%	772	690	0.894	4.1	11.5	710
M34-SCC-AWA1.5%	750	635	0.847	3.8	11.3	680
M35-SCC-AWA 2%	721	560	0.777	3.5	11.1	640
M36-SCC-AWA 3%	697	523	0.750	3.0	11.0	635
M37-SCC-AWA 0%	813	632	0.777	6.8	12.1	775
M38-SCC-AWA 0.5%	855	755	0.883	5.0	11.5	755
M39-SCC-AWA 1%	867	810	0.934	3.4	10.8	730
M40-SCC-AWA1.5%	855	711	0.832	3.1	10.7	700
M41-SCC-AWA 2%	811	650	0.801	2.9	10.6	655
M42-SCC-AWA 3%	790	622	0.787	2.7	10.5	645
M43-SCC-AWA 0%	355	234	0.659	8.6	11.8	660
M44-SCC-AWA 1%	370	277	0.749	5.6	12.2	630
M45-SCC-AWA 0%	366	255	0.697	6.5	12.9	640
M46-SCC-AWA1%	378	288	0.762	3.9	12.9	620
M47-SCC-AWA 0%	370	265	0.716	5.0	12.9	650
M48-SCC-AWA 1%	398	298	0.749	4.4	12.7	630
M49-SCC-AWA 0%	354	244	0.689	5.9	12.5	660
M50-SCC-AWA 1%	388	277	0.714	7.4	12.3	620

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سلوك الخرسانة ذاتية الدمك المصبوبة تحت الماء

تتجه انظار العالم اليوم الى استخدام الخرسانة ذاتية الدمك لما لها من مميزات متعددة. ولما تتميز به الخرسانة ذاتية الدمك من انسياب و سيولة كبيرة مما يجعل العاملين في هذا المجال قد يتخوفون من تطبيقاتها في الاعمال الانشائية تحت الماء تحسبا لتفككها بفعل الغسيل المائى لها. في هذه الدراسة تم اعداد 50 خلطة خرسانية منها 44 خلطة خرسانة ذاتية الدمك و 6 خلطات خرسانة معتادة لعمل المقارنات اللازمة. وكان الاعتماد الاساسى للبحث استخدام اضافة لتقليل التفكك بفعل الغسيل المائى وبنسب متفاوتة مع تغيير بعض المعاملات الاخرى للخرسانة ذاتية الدمك مثل محتوى الاسمنت و نسبة الماء الى المواد الاسمنتية ونسبة السوبربلاستيسيزر وكذلك نسبة الركام الناعم الى الركام الشامل وذلك بغرض الحصول على افضل النسب للخرسانة ذاتية الدمك لتحقق المتطلبات القياسية للاختبارات الخاصة بالصب تحت الماء. تم قياس الغسيل المائى للخرسانة تحت الماء بطريقتين الفقد في الوزن و قيمة الاس الهيدروجينى. كما تم قياس اجهادات الضغط لجميع الخلطات بعد 28 يوم للتى صبت تحت الماء وكذلك التى صبت في الظروف العادية (في الهواء) بغرض تحديد قيمة الاجهاد النسبى وهو اجهاد الخرسانة تحت الماء مقسوما على اجهاد الخرسانة في الظروف العادية.

أظهرت النتائج أن الفقد فى الوزن بفعل الصب تحت الماء للخرسانة ذاتية الدمك تم تخفيضه بنسبة حتى 44% وتحسين المقاومه النسبية التى وصلت حتى 93% بفعل اضافة مادة مقاومة الغسيل المائى واختيار افضل النسب للمتغيرات السابق ذكرها وبذلك امكن ادراج الخرسانة ذاتية الدمك للمواصفات القياسية التى نصت على الا يزيد الغسيل المائى عن 8% كفقد فى الوزن والا يقل الاجهاد النسبى عن 70% فى حين تجاوزت كثير من الخلطات هذه النسب قبل الاختيار الامثل لنسب الخلط والاضافات الخاصة بمقاومة الغسيل المائى. تم تقنين قيمة الاس الهيدروجينى للماء المعكر بفعل غسيل الخرسانة بما لا يزيد عن 12.5 بما يقابل 8% فقد فى الوزن. اظهرت الدراسة أيضا الكفاءة العالية للخرسانة ذاتية الدمك المصبوبة تحت الماء بالنسبة للخرسانة المعتادة اذا ما استخدمت اضافات مقاومة الغسيل المائى و النسب المثلى للخلطة بينما اظهرت النتائج كفاءة الخرسانة المعتادة المصبوبة تحت الماء عن نظيرتها الخرسانة ذاتية الدمك عند عدم استخدام اضافات المقاومة للغسيل المائى و النسب المثلى للخلطات ذاتية الدمك.

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