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BOND STRENGTH OF SELF-COMPACTING REINFORCED CONCRETE BEAMS EXPOSED TO SALINE WATER

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Abstract: This study includes a series of bond tests related to reinforced concrete beams with rectangular cross section (140x150) & span of 600 mm that are provided with shear reinforcement. The specimens are tested as simply supported beams with one point load with strain reading in steel bar by strain indicator placed in a hole (recess) prepared for this purpose. Displacement between the steel bar and the concrete at the free end of bar has been measured. Three groups of beams have been tested to study the effect of many variables on bond strength for Self Compacting Concrete (SCC) and conventional reinforced concrete (CC). The variables are: [steel bar diameter (8, 12 and 16) mm, concrete compressive strength (30, 60) MPa and type of curing (tap water continuous curing, saline water wetting and drying, saline water continuous exposing) for a time of (90 days). The study also involves the effect of each variable on bond strength and comparison between the results of all the specimens of SCC and CC bond stress-slip relationships. The results of comparison between all specimens of SCC and CC bond stress-slip relationships show that, the CC bond strength is lower than the SCC bond strength in two cases of curing (tap water continuous, saline water continuous exposing), but in case of saline water wetting and drying, the CC bond strength is higher than SCC bond strength.

KeyWord: *Bond Strength, Self Compacting & Conventional Concrete, Beam Test, Exposing Saline Water.*

قوة الربط للعتبات الخرسانية المسلحة ذاتية الرص المتعرضة الى محلول ملحي

الخلاصة: تتضمن هذه الدراسة سلسلة من الفحوصات الربط الخاصة بعتبات خرسانية مسلحة بمقطع مستطيل (140*150 ملم) وبطول (600 ملم) ومزود بتسليح عرضي (تسليح قص)، وتم فحص النماذج كعتبات بسيطة الاسناد وبنقطة حمل مع قياس الانفعال في حديد التسليح بواسطة متحسس الانفعال من خلال تجويف خاص اعد لهذا الغرض وكذلك تم قياس الانزلاق النسبي بين القضيب والخرسانة المحيطة به وذلك في النهاية الحرة للقضيب. تم تقسيم العتبات الى ثلاث مجموعات لدراسة تأثير بعض المتغيرات على مقاومة الربط للخرسانة العالية الربط. المتغيرات التي تم دراستها هي : (قطر حديد التسليح(8,12 و16 ملم) ،مقاومة الانضغاط للخرسانة ذاتية الرص والعادية (30 و 60 ميكا باسكال) ونوع المعالجة التي تعرضت لها الخرسانة بنوعيها (ماء اعتيادي باستمرارية ، محلول ملحي تجفيف وترطيب و محلول ملحي باستمرارية)) حيث تم دراسة تأثير كل متغير على مقاومة الربط بين حديد التسليح والخرسانة كذلك تضمنت الدراسة اقتراح 6 معادلات لربط مقاومة الترابط بين الخرسانة وحديد التسليح مع المتغيرات المذكورة اعلاه . بينت نتائج الفحوصات ان مقاومة الربط تزداد بزيادة مقاومة الانضغاط وتقل بزيادة قطر حديد التسليح . وبالاعتماد على نتائج الانحدار الا خطي لنتائج العمل التجريبي، تم استنتاج 6 معادلات الاولى تربط المتغيرات (قطر حديد التسليح ،مقاومة الانضغاط) مع مقاومة الربط . وكذلك تضمنت هذه الدراسة مقارنة بين نتائج أظهرت المقارنة بين كُلّ نماذج SCC وCC من خلال علاقة قوة السحب مع الانسحاب بأنّ CC لَها إجهاد ربط أعلى مِن SCC .

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1. Introduction

The term "Self Compacting Concrete" (SCC) refers to a "new" special type of concrete mixture. SCC is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weigh, completely fills formwork and achieves full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. SCC offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water/cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and structures. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction[1].

Bond strength results from a combination of several parameters, such as the mutual adhesion between the concrete and steel interfaces and the pressure of the hardened concrete against the steel bar or wire due to the drying shrinkage of concrete. Additionally, friction interlock between the bar surface deformations and the concrete caused by the micro movements of the tensioned bar results in an increased resistance to slippage. The total effect of this is known as bond[2] **.**

Durability of reinforced concrete and the problems associated with it are nowadays a matter of considerable concern. It can be defined as the ability of concrete to retain its quality and serviceability without deterioration when exposed to its environment during its design life. In general, deterioration of structures takes place due to a number of physical, chemical, or mechanical factors.

The Arabian Gulf seaboard is one of the world's aggressive environments to concrete. Concrete structures in the Gulf States show an alarming degree of deterioration within a short span of 10 to 15 years [3] of the concrete life.

In Iraq, deterioration problems of reinforced concrete structures come mainly from extraneous aggressive ions attack represented by sulfates and chlorides in underground water especially in the southern regions of Iraq and high gypsum sulfates in the soil.

The understanding of bond behavior between reinforcing steel and concrete is considered to the design of reinforced concrete structures. The bond of deformed reinforcement in concrete is a complicated mechanism. Bond behavior is the interaction of the bar with the concrete, including the mode of failure, i.e., slip of the bar by pullout or splitting failure. The development length of a reinforcing bar is the length that the bar must be embedded to fully yield the bar while anchored in concrete.

When reinforcing bars are embedded into concrete and consequently loaded in tension, a certain bond stress is associated with this load development in the concrete.

This bond stress is a nonlinear stress and is a function of load, reinforcing bar material properties and reinforcing bar geometric properties. Bond stress is higher near the end of the bar that is loaded and drops at the opposite end. Qualitatively, if the bond stress in the first part of the bar does not reach some critical point, the rest of the bar beyond that first part will not be required to transfer force from itself to the concrete [4]. For the entire bar to transmit force, the embedded portion of the bar closest to the load must reach this critical point; slip some unnoticeable amount, and then redistribute the bond stresses. This cycle continues until the entire bar transmits load from itself to the surrounding concrete.

Bond strength is comprised of three components, friction, adhesion (dependent on the bar surface condition), and bearing (dependent on the bar deformation pattern). Bond components can be seen in Figure [1]. When adhesion is small and neglected, the remaining components form a resultant stress that can be further broken into longitudinal and radial bond stresses (5).

Bond equations generally relate bar stresses to bond lengths. When bond stresses are studied, it is common practice to assume an average distribution of the bond stresses to compute the mean working bond strength. In general terms, this means that bond stress equation is:

$$U=\frac{A_b \times f_s}{L \times \pi \times d_b} \qquad \text{Eq. (1)}$$

Where:

u = bond stress (MPa).

d_b = the bar diameter (mm).

f_s = the steel stress at bond failure (MPa).

A_b = the area of the bar being developed (mm^2).

L = the length of bar bonded or exposed to the concrete (mm).

The mean bond stress can be converted to working bond strength, U, through equilibrium concepts. The working force in the bar can be found by taking the bond stress and multiplying by the area of the bar in contact with the surrounding concrete. In other words, the bond strength, $U = uL\pi\ d_b$, is equal to bar force, $P=A_b f_s$

Bond failure must be defined for the purpose of normalization between various bond studies. A logical way to define this failure point would be some specific value for free-end displacement, or the load that causes the unloaded end slip. Small values of free end displacement generally indicate that bond failure has occurred. Previous tests established this limit as a free-end displacement of 0.002-in (0.0508 mm). Therefore, all references to bond strength should be defined herein as the load causes a free-end displacement of 0.0508 mm, (0.002 in.) [5].

Reinforced concrete design is based on an effective bond between concrete and the reinforcing bars. The concrete bond strength should be sufficient to prevent bond failure. The effectiveness of bond is affected by the position of the embedded bars and the quality of concrete as cast. An adequate concrete cover is necessary in order to properly transfer bond stresses between steel and concrete.

Poor bond often results from a failure of the concrete to fully encapsulate the bar during placing, or bleed and segregation of the concrete before hardening which reduce the quality of contact on the bottom surface. SCC fluidity and cohesion minimize these negative effects, especially for top bars in deep sections.

Whether bond properties are generally enhanced when SCC is used, for a given compressive strength, the formulas used in the codes should be used. (1)

2. Research Significance

1. The main purpose of this study is to investigate the individual and combined effects of some variables on bond strength of Self-Compacting Concrete.
The main factors that affect bond strength are bar diameter, compressive strength.
2. investigating the durability of Self-Compacting Concrete under harsh environmental conditions represented by immersion, wetting and drying cycles of the concrete samples in saline water containing high percentages of chloride and sulfate ions, The negative ion concentration was set to equivalent to their concentrations in the ground water of some regions in southern Iraq [6], since it is known that the environmental loading causes maximum damage to concrete in the tidal zone. The effect of immersing, wetting and drying cycles as compared to the standard exposure samples in saline water for 90 days after casting, have been investigated through its effect on many properties such as compressive, bond strength, and modulus of rupture.

3. Experimental work

This study focuses on producing self-compacting concrete (SCC) with specific compressive strength (30and60) MPa using the modification of (ACI 211.1[7]) mix design method according to the requirements of EFNARC [8]

The test program consists of fabricating and testing 20concrete beam specimens. Four different variables are investigated, these variables are:
1- Concrete type (self compacting concrete and conventional concrete).
2- Concrete compressive strength (30and 60) MPa.
3- Bar diameter (8, 12, and 16) mm.
4- Type of curing (continuous curing in tap water, wetting and drying in saline water 24 hours for each, and continuous exposing to saline water).

The beam specimens are divided into three groups. Each group consists of different specimens with different steel reinforcement diameters as listed table (1) . The concrete cover is taken as constant at 20 mm as shown in Fig (1).

3.1 Materials

3.1.1 Cement

Ordinary Portland cement (type 1) complying with ASTM C 150[9] and the Iraqi Standard Specification I.Q.S. No.5, 1984 requirements. [10]

3.1.2 Fine Aggregate

The Natural siliceous sand is complying with ASTM C 33[11] and I.Q.S. No.45, 1984[12] requirements with fineness modulus, specific gravity and absorption of 3.18, 2.7 and 1.5% respectively and Sulfate content (SO3 %) is 0.34% was used in this work.

3.1.3 Coarse Aggregate

The ideal coarse aggregate used for the production of SCC should be clean, angular, or rounded of 10-20 mm maximum size. The maximum coarse aggregate size used in this study is chosen to be 14mm, 100% crushed aggregate with specific gravity and absorption of 2.64 and 0.57 %, respectively was used. the grading of aggregate was within the limits of ASTM C33[11] and I.Q.S. No.45, 1984[12]grading requirements. Sulfate content (SO3%) is 0.06%.

3.1.4 Limestone Powder (L.S.P.)

Limestone powder has been used as a filler for concrete production for many years. It has been found to increase workability and early strength, as well as to reduce the required compaction energy **(13)**

A fine limestone powder with surface area (3100cm²/gm) is used to avoid excessive heat generation, enhance fluidity and cohesiveness, improve segregation resistance and increase the amount of fine powder in the mix (cement and filler). According to EFNARC, the fraction less than 0.125 mm will be of most benefit [8]. The specific gravity of the LPS was 2.7.

3.1.5. Super plasticizer

To produce self-compacting concrete, the use of a superplasticizer is essential. The super plasticizer used is based on polycarboxylic ether. It had a trade mark of Glenium 51[14]. Glenium 51 is free from chlorides and complies with ASTM C494, types A and F. It is compatible with all Portland cements that meet recognized international standards.

3.1.6. Reinforcing Steel

Deformed steel bars of (8, 12, and 16) mm are used.

3.1.7. Preparation of the Saline Solution

One of the principal problems of concrete durability is the external attack of sulfate and chloride salts, especially those present in soil and underground water in southern parts of Iraq. The underground water analysis report, prepared by the National Center for Geological Survey and Mining (16) shows that the chloride ion concentration ranges between (20000-40000) ppm and the sulfate ion concentration ranges between

(5000-7000) ppm. The cat-ions concentration is (10000-20000) ppm for sodium, (1500-2000) ppm for magnesium and (1000-1500) ppm for calcium (80). The salts used in preparing the solution are pure NaCl, $CaCl_2.2H_2O$ and $MgSO_4.7H_2O$. Potable water, with ions concentrations shown in Table (2), is used as a solvent for these salts. Table (1) illustrates the types and concentrations of salts used in curing solution and the actual anions and cat-ions provided by such salts and those coming from potable water [6].

Table (1) Types and concentrations of salts and ions (including those in potable water) used in curing solution.

Type of salt	Concentration		Salt content% by wt. of curing solution	Anions		Cations	
	ppm	gm/l		Type	Concentration ppm	Type	Concentration ppm
NaCl	45100.4	45.1	45.1	Cl^-	30083.5	Na^+	17750
$CaCl_2$. $2H_2O$	5512.5	5.5	0.55			Ca++	1563
$MgSO_4.7H_2O$	17967.7	17.967	1.79	SO_4^{--}	7125.7	Mg++	1801

3.2 Specimens Details

Table (2) gives the details of the tested specimens. Notations used are as follows:

The specimen B2-30, number 30 represents a specimen with nominal concrete compressive strength of 30 MPa**.** One mould is used in the fabrication of beams. This mould is made of plywood. The dimensions of the beams are (140 x 150 x 600) mm limited on the basis that it will meet the bond requirements, which are shown in Fig. (1). All beams are reinforced by two deformed reinforcing bar. Transverse reinforcement consists of 8 mm bar, which has yield strength of 400 MPa made into vertical closed stirrups and spaced at 60mm throughout the shear span for all the tested beams, as shown in Fig. (1).

Table (2) Beam specimen properties

Group	Design Nation	Concrete type	Diameter of Steel Bar(mm)	Cover (c) mm	Type of curing
A	A1-30	CC	12	20	T.W.C.C. *
	A2-30	SCC			T.W.C.C. *
	A3-30	CC			S.W.W.D.*
	A4-30	SCC			S.W.W.D.*
	A5-30	CC			S.W.C.E.*
	A6-30	SCC			S.W.C.E.*
	A7-60	CC			T.W.C.C. *
	A8-60	SCC			T.W.C.C. *
B	B1-30	SCC	8	20	S.W.W.D.*
	B2-30	SCC			S.W.C.E.*
	B3-60	SCC			S.W.W.D.*

	B4-60	SCC			S.W.C.E.*
C	C1-30	SCC	16	20	S.W.W.D.*
	C2-30	SCC			S.W.C.E.*
	C3-60	SCC			S.W.W.D.*
	C4-60	SCC			S.W.C.E.*

*T.W.C.C. : tap water continuous curing .
*S.W.W.D. : saline water wetting and drying .
* S.W.C.E. : saline water continuous exposing.

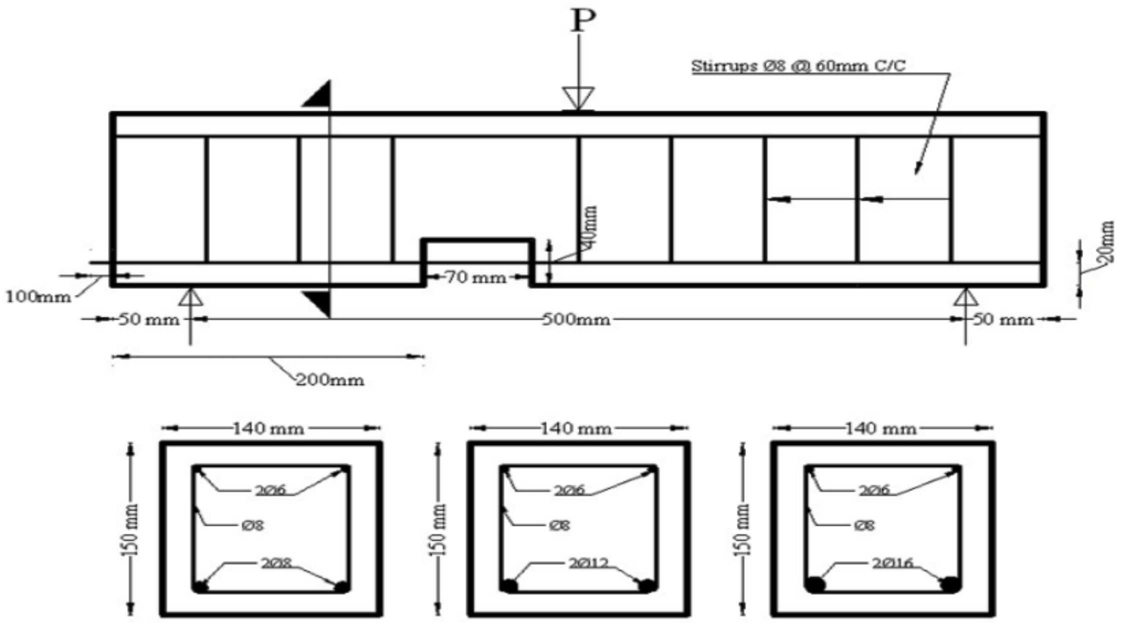

Figure 1. Details of Beams.

4. Test Results

4.1 Testing of fresh SCC mixes

Two tests for determining the fresh properties of SCC properties were implemented, these were: the slump flow and the L-box[8]. These tests were chosen for their simplicity to be used in construction sites and for their good results that well represent SCC fresh properties.

The slump flow and T50 time are tests to assess the flowing ability and the flow rate of SCC in the absence of obstructions. Slump test can also be used to indicate segregation resistance of SCC to an experienced user (12). As specified by EFNARC (8), the fresh concrete must have a maximum spread (slump flow diameter) under the following conditions:

1. Slump flow diameter (D) should not be less than 650 mm and not more than 800mm.
2. The flow behavior should be without any indication of segregation.

Table (3) shows the results of all the mixes which have acceptable values of slump flow according to EN 206-1: 2000 and EFNARC specifications except S30 which is less than 650mm.

On the other hand, the L-box test was used to assess the passing ability of SCC to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking)(8,1). As shown in Table (3), all the mixes have acceptable values of the passing ability ratio.

Table (3): The Results of Experimental Properties of Fresh Self Compacting Concrete.

Mix notation	Nominal f'c (MPa)	Slump flow (mm)	T50 Sec.	L-box (h2/h1)	T20 Sec.	T40 Sec.
30S	30	635	5	0.94	2	4
60S	60	700	7	0.86	3	5

4.2 Testing of hardened SCC &CC

4.2.1 Compressive Strength

Standard cylinders measuring (l50×300) mm are cast and tested to determine the compressive strength of the concrete mixes at the age of testing (90days). Three cylinders are cast and tested with each concrete batch. Two concrete groups (A, B) are used for nominal compressive strengths (30,60) MPa respectively for SCC and CC. The results of this test indicate that, the measured concrete compressive strength is, as shown in Table (4), the compressive strength for CC (30,60 MPa) in case of curing S.W.W.D. larger than case S.W.C.E. and the compressive strength for SCC (30,60 MPa) in case of curing S.W.W.D is larger than case S.W.C.E.

Table (4): Compressive Strength of Investigated Concrete Compressive beam Specimen

Group		Nominal f'c (MPa)	Actual SCC f'c (MPa)	f'c average (MPa)	Actual CC f'c (MPa)	f'c average (MPa)
A	A1	30	29.7	31.2	37.35	36.5
			31.7		34.5	
			32.25		37.9	
	A2	30	34.8	35.5	30.27	31
			33.3		32.8	
			38.4		29.9	
	A3	30	33.1	32.05	29.4	29
			32.25		30.27	
			30.8		27.16	
B	B1	60	61.5	61.6	-	62.4
			61.4		63	
			61.9		61.8	
	B2	60	-	64.8	57.6	58.3
			60.5		57.6	
			69.1		59.8	
	B3	60	60.9	60.3	57.7	57.6
			61.2		-	
			58.3		53.5	

A1// SCC 30 + CC 30 (T.W.C.C.) , A2// SCC 30 + CC 30 (S.W.W.D.)
A3// SCC 30 + CC 30 (S.W.C.E.) , B1// SCC 60 + CC 60 (T.W.C.C.)
B2// SCC 60 + CC 60 (S.W.W.D.) , B3// SCC 60 + CC 60 (S.W.C.E.)

4.2.2 Modulus of Rupture

The mean modulus of rupture for all concrete mixes is determined and the results are shown in Table (5). Results indicate that, the two types of curing concretes exhibited difference in modulus of rupture for SCC& CC (30,60 MPa) in same curing age (90 days). Results presented in Table (5) indicate that, the modulus of rupture of SCC (60 MPa) is better than the modulus of rupture of SCC (30 MPa), but not as expected to consist ratio bound (l/2 fc). The increase of modulus of rupture of SCC (60) MPa when compared with SCC (30 MPa) is (5%) but the increase of modulus of rupture of CC (60 MPa) when compared with CC (30) MPa is (7%).

Table (5) Results of Flexural Strength (f_r) (MPa)

Mix	f_r
CC 30 S.W.C.E.	3.3
CC 30 S.W.W.D.	4.2
SCC 30 S.W.C.E.	3.54
SCC 30 S.W.W.D.	3.63
CC 60 S.W.C.E.	4.74
CC 60 S.W.W.D.	4.83
SCC 60 S.W.C.E.	4.56
SCC 60 S.W.W.D.	5.76

4.2.3 Dry Density

The dry bulk density, for both types of concrete (SCC and CC) is presented in Table (6). Results show that, the gain of bulk density of SCC is slightly higher than those of the CC. In general, the density increases with time of curing, for both types of concrete (SCC and CC) due to the hydration of cement. The densities of both types of concrete are close to each other but there are some differences in values of densities from specimens exposure to saline water (continuous exposing & wetting and drying curing) in which results show a decrease in density with time of curing, for both types of concrete (SCC and CC).

Table (6) Dry Density for SCC & CC

Mix	Age (days)	Density (Kg/m^3)	Mix	Age (days)	Density (Kg/m^3)
CC30 S.W.C.E.	28	2320	SCC 30 S.W.C.E.	28	2434
	60	2388		60	2475
	90	2365		90	2420
CC30 S.W.W.D.	28	2390	SCC30 S.W.W.D.	28	2420
	60	2468		60	2461
	90	2409		90	2432

CC60 S.W.C.E.	28	2411	SCC60 S.W.C.E.	28	2420
	60	2423		60	2448
	90	2416		90	2433
CC60 S.W.W.D.	28	2423	SCC 60 S.W.W.D.	28	2412
	60	2477		60	2447
	90	2451		90	2426

4.3 Bond Stress

Stress in the test bar is calculated by converting the measured steel strain (from test) into stress using the modulus of elasticity (E_s=200000MPa). Bond stress then is calculated assuming a uniform distribution of bond stress along the embedded bar.

Equating the tensile force on the bar with the total bond force on the surface area of the bar yields:

$$l_d \pi \, d_b U = A_b \, f_s \qquad \text{Eq. (2)}$$

$$U = \frac{d_b \ f_s}{4 \, l_d} \qquad \text{Eq. (3)}$$

Where: U: average bond stress (MPa).
d_b: bar diameter (mm).
f_s: tensile stress in reinforcing bar (MPa).
L_d: development length (mm).

All tested beams test show that all cracks, which represent flexural cracks, start from the tensioned face towards the compression zone within or near the maximum moment region due to the excessive slip in the free end of the steel bars. These flexural cracks are not associated with any longitudinal splitting cracks along the tensioned bar (splitting crack is defined as the longitudinal crack that connects two successive flexural cracks along the steel bar) .The beam specimens show very limited flexural cracks due to the brittle behavior of high strength concrete used in these specimens (13,14).

Tables (7) and (8) indicate the type of failure which takes place in each group of specimens. Also, this table gives values of the failure bond stresses at failure force and maximum slip taking place prior to failure of the specimens for SCC and CC. It is noticed that، all beam specimens fail by flexural and shear failure except beam specimens (A4-30, Cl-30, and C3-60), which show pull out failure. Involving failure by flexural, shear and pull out failure rather than by splitting failure for all beam specimens belong to the following reasons:

1. The beams exposure to saline water (continuous curing and wetting &drying) , this is due to the drop in concrete strength and exposure to such an extent that concrete causes flexural , shear and pull out failure rather than splitting failure because the concrete becomes very weak to resist even a small applied load .
2. Embedment length provided makes possible to produce flexural, shear and pull out failure rather than splitting failure. The provided embedment length (199 mm) unlimited value causes excessive slip at the free end of the bars. Excessive slip is

associated with a rapid increase in the movement of the free end of the bar with only slight increase in the applied load.

3. Short length of beam causes weakness in strength of beam against flexural, shear failure.

However, this beam is characterized by higher development length which may be but not limited to, the cause of such mode of failure (where adequate embedment length is provided in a large mass of concrete, it is not possible to produce a bond (flexural, shear and pull-out) failure with standard deformed bars)(15).

Table (7) test results of flexural and shear strength of the beams specimens

Specimen Identification	Reinforcing	Type of conc.	Type of curing	f'c MPa (90 days)	Failure force KN	P cal. Flexural KN	P cal. Shear KN	Failure mode
A1 - 30	2Φ12	CC	T.W.C.C.	36.5	56	111.9	137.76	Shear
A2 - 30	2Φ12	SCC	T.W.C.C.	31.2	154	109.34	135.58	Pull-out
A3 - 30	2Φ12	CC	S.W.W.D.	31	132	109.23	135.49	Shear
A4 - 30	2Φ12	SCC	S.W.W.D.	35.5	144	111.48	137.48	shear
A5-30	2Φ12	CC	S.W.C.E.	29	104	108.004	134.55	Shear
A6-30	2Φ12	SCC	S.W.C.E.	32.05	116	109.8	135.96	Shear
A7-60	2Φ12	CC	T.W.C.C.	62.5	126	118.194	147.42	Shear
A8-60	2Φ12	SCC	T.W.C.C.	61.6	132	118.06	147.13	Shear
B1-30	2Φ8	SCC	S.W.W.D	31.9	54	55.5	138.01	Flexural
B2 - 30	2Φ8	SCC	S.W.C.E.	31.8	56	55.5	137.96	Shear
B3-60	2Φ8	SCC	S.W.W.D	66.2	52	57.4	150.92	Flexural
B4 - 60	2Φ8	SCC	S.W.C.E.	62.5	80	57.31	149.2	Flexural
C1-30	2Φ16	SCC	S.W.W.D.	34.03	132	167.97	134.6	Flexural
C2-30	2Φ16	SCC	S.W.C.E.	30.1	142	161.62	132.9	Flexural
C3-60	2Φ16	SCC	S.W.W.D.	62.1	156	189.97	144.87	Pull-out
C4-60	2Φ16	SCC	S.W.C.E.	61.15	110	189.56	144.6	Flexural

Table (8) Test Results of Beam Specimens

Specimen Identification	Reinforcing	Type of concrete	Type of curing	Actual f'c MPa	Maximum Slip (mm)	Failure force kN	Max. bond strength MPa
A1 - 30	2Φ12	CC	T.W.C.C.	36.5	0.033	56	9.7
A2 - 30	2Φ12	SCC	T.W.C.C.	31.2	0.061	154	28
A3 - 30	2Φ12	CC	S.W.W.D.	31	0.03	132	29.4
A4 - 30	2Φ12	SCC	S.W.W.D.	35.5	0.16	144	28
A5-30	2Φ12	CC	S.W.C.E.	29	0.09	104	24.4
A6-30	2Φ12	SCC	S.W.C.E.	32.05	0.064	116	14.1
A7-60	2Φ12	CC	T.W.C.C.	62.5	0.079	126	20.4
A8-60	2Φ12	SCC	T.W.C.C.	61.6	0.065	132	30
B1-30	2Φ8	SCC	S.W.W.D	31.9	0.016	54	28.7
B2 - 30	2Φ8	SCC	S.W.C.E.	31.8	0.05	56	19
B3-60	2Φ8	SCC	S.W.W.D	66.2	0.028	52	26.16

B4 - 60	2Φ8	SCC	S.W.C.E.	62.5	0.031	80	26.2
C1-30	2Φ16	SCC	S.W.W.D.	34.03	0.055	132	30
C2-30	2Φ16	SCC	S.W.C.E.	30.1	0.095	142	6.9
C3-60	2Φ16	SCC	S.W.W.D.	62.1	0.075	156	20.4
C4-60	2Φ16	SCC	S.W.C.E.	61.15	0.058	110	15.6

4.4 *Effects of the Investigated Parameters on Bond Stresses*

As mentioned earlier, the studied parameters in this work are the concrete type (SCC or CC), concrete compressive strength, and steel reinforcement diameter. The test results, which reveal the effect of these parameters on the bond strength, are discussed in this section.

4.5 *Effects of Bar Diameter on Bond Stress-Slip Relationship*

Many investigators (6, 17, 18, 19, 20, and 21), noticed that the bond strength increases with the decrease of bar diameter. The test results of the study confirm this observation. The effect of bar diameter on the bond behavior was investigated in this study by the comparison three different bar diameters. The bar diameters are 8, 12 and 16 mm. To study the bar diameter size influence on the bond strength, concrete cover and embedment length are fixed as functions of the bar diameter.

In addition، Figures (2) to (5) clearly show the effect of bar diameter on bond stress-slip relationship for compressive strength (30,60 MPa) for SCC and curing type saline water wetting and drying (s.w.w.w.), saline water continuous exposing (S.W.C.E.) Figures (2) to (5) show the bond stress slip curves for specimens of three different bar diameters. It is obvious that, the specimens with the small bar diameter have greater bond strength than the specimens with larger diameter bars and also for a given bond stress, the corresponding slip is less for bars with small diameter (8 mm), as compared with the larger diameter bar (16 mm)

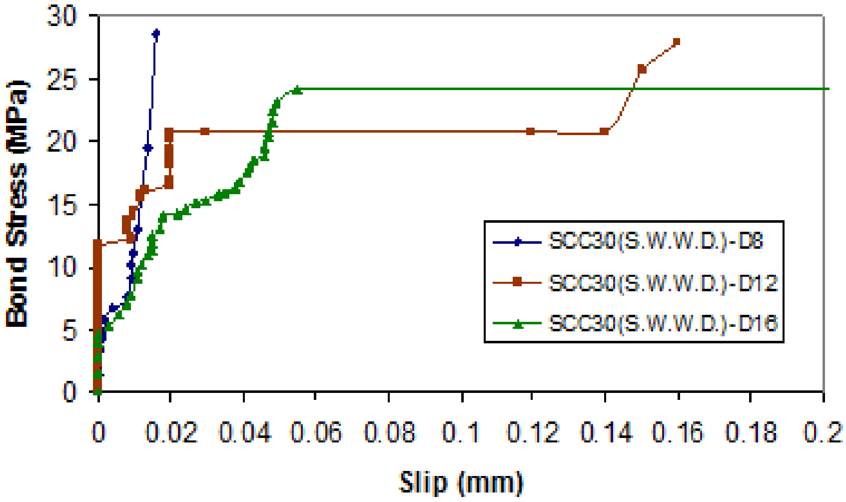

Figure 2.Effect of Bar Diameter in SCC (S.W.W.D.) on Bond Stress-Slip Relationship for Compressive Strength of 30MPa

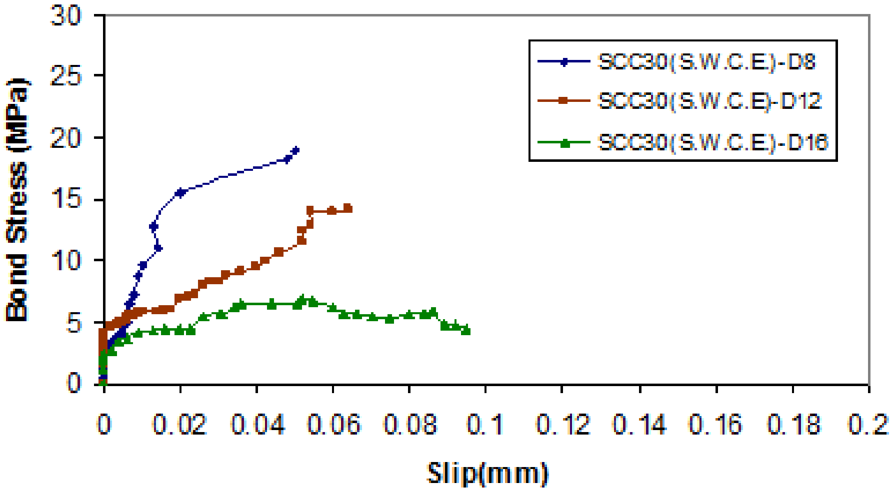

Figure 3. Effect of Bar Diameter in SCC (S.W.C.E.) on Bond Stress-Slip Relationship for Compressive Strength of 30MPa.

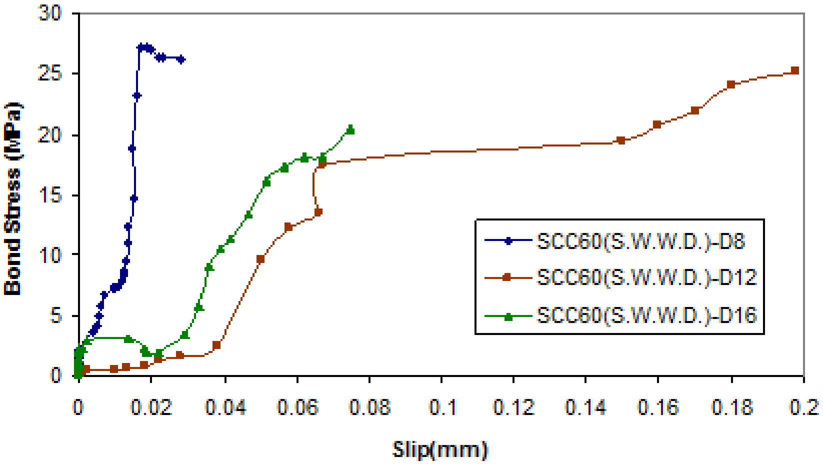

Figure 4. Effect of Bar Diameter in SCC (S.W.W.D.) on Bond Stress-Slip Relationship for Compressive Strength of 60 MPa.

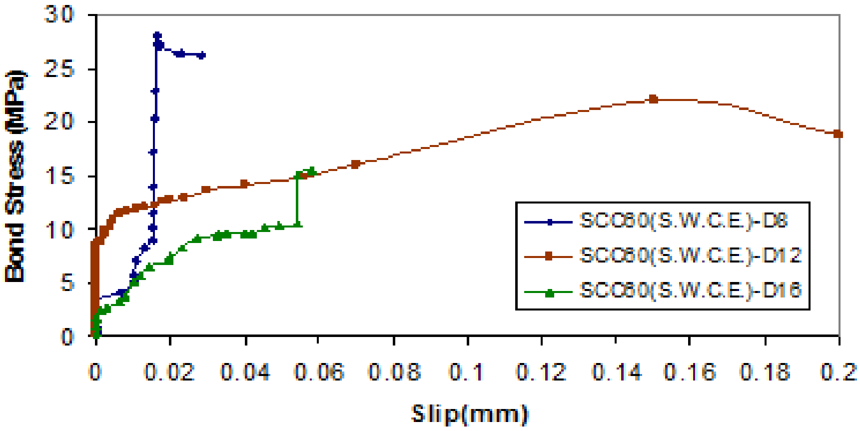

Figure 5. Effect of Bar Diameter in SCC (S.W.C.E.) on Bond Stress-Slip Relationship for Compressive Strength of 60 MPa.

4.6 Effects of Concrete Compressive Strength on Bond Stress

From the results of the tested specimens, it is clear that the increase in concrete compressive strength results in an increase in the bond strength. The experimental results of the bond stress and the corresponding slip are drawn in Figures (6) to (11) for the same steel bar diameter, but

with different concrete compressive strengths. From these figures, it is clear that with the increase of compressive strength of concrete, the bond strength between the concrete and the steel bar increases in case saline water continuous exposing, but in case of saline water wetting and drying, curing the increase of compressive strength of concrete, the bond strength between the concrete and the steel bar decrease.

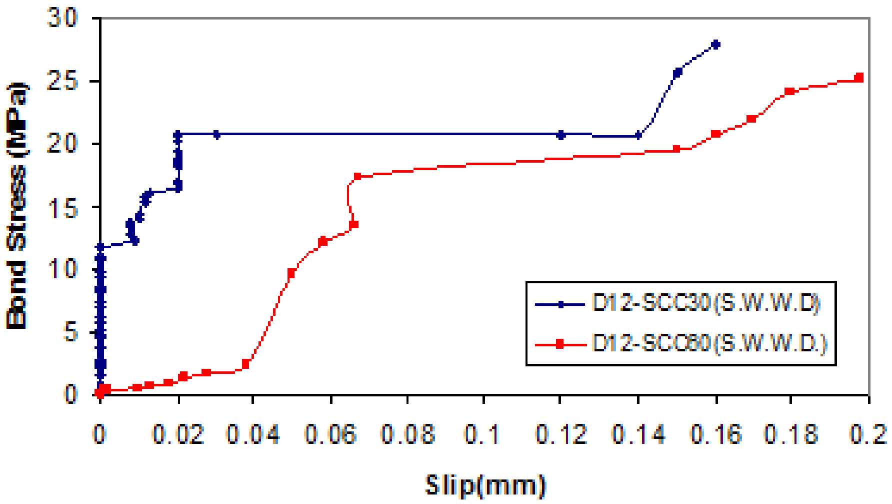

Fig. (6) Effect of Compressive Strength of SCC(S.W.W.D.) on Bond Stress-Slip Relationship for Bar Diameter of 12 mm

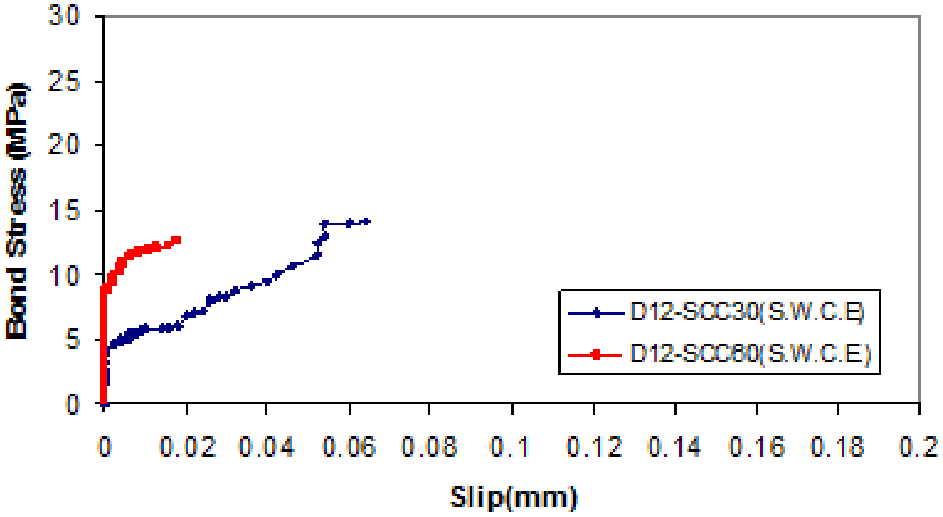

Figure7. Effect of Compressive Strength of SCC(S.W.C.C.) on Bond Stress-Slip Relationship for Bar Diameter of 12 mm

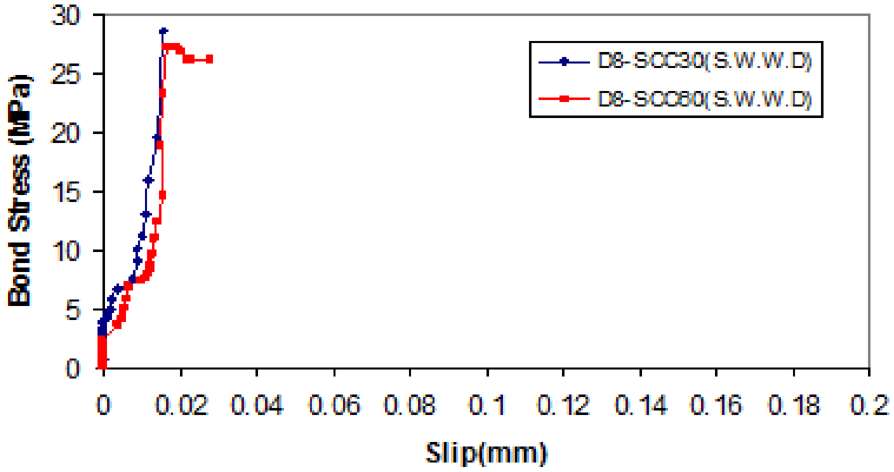

Figure 8. Effect of Compressive Strength of SCC(S.W.W.D) on Bond Stress-Slip Relationship for Bar Diameter of 8 mm

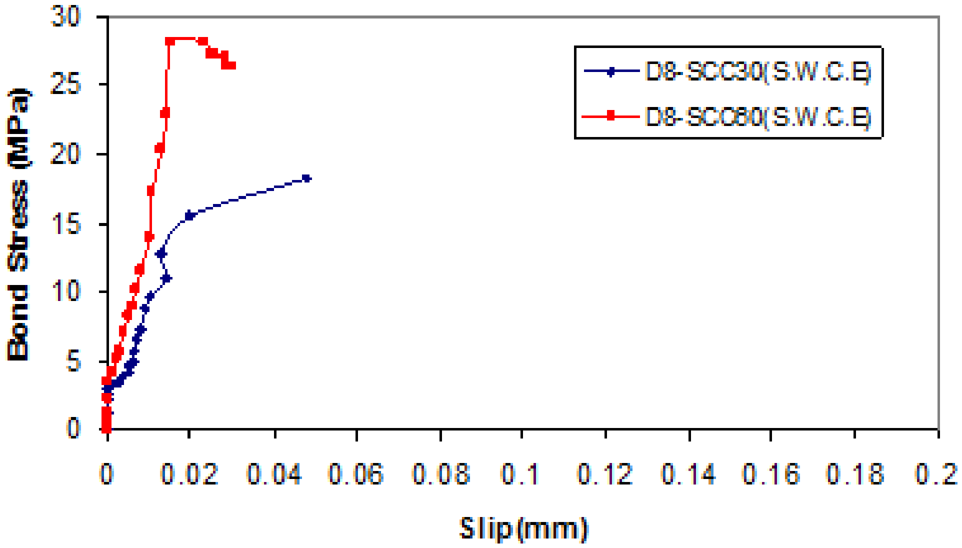

Figure 9. Effect of Compressive Strength of SCC(S.W.C.C.) on Bond Stress-Slip Relationship for Bar Diameter of 8 mm

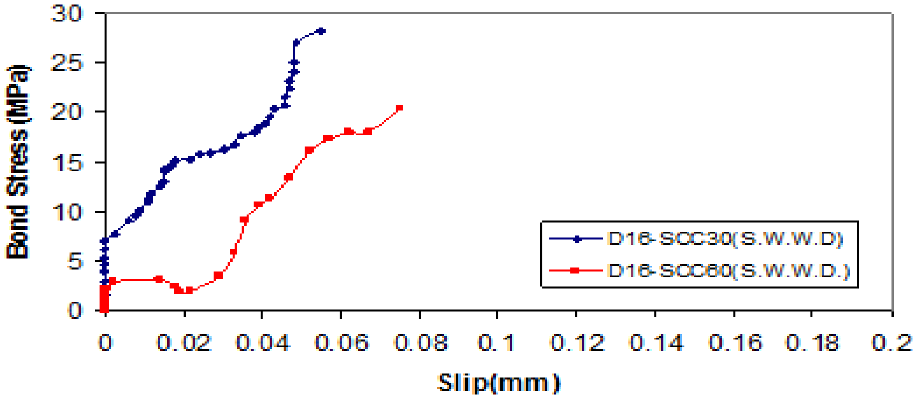

Figure10. Effect of Compressive Strength of SCC(S.W.W.D) on Bond Stress-Slip Relationship for Bar Diameter of 16 mm

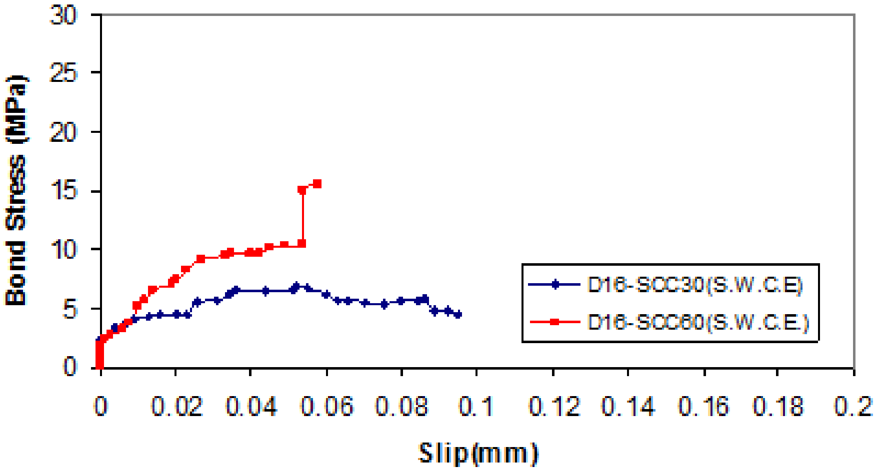

Figure11. Effect of Compressive Strength of SCC(S.W.C.E.) on Bond Stress-Slip Relationship for Bar Diameter of 16 mm

4.7 Concrete Type (Self Compacting Concrete and Conventional Concrete)

The experimental results of the bond stress and the corresponding slip are drawn in Figures (12) to (16) for the same steel bar diameter, and compressive strength with different concrete types (SCC and CC) for two types of curing (saline water wetting and drying and saline water continuous) .From these figures, it is clear that, the SCC bond strength is higher than the CC bond strength in case saline water continuous exposing, but in case of saline water wetting and drying exposing the SCC bond strength is lower than CC bond strength .In some times the results of the bond stress and the corresponding slip are not logically because of the unexpected behavior of concrete (SCC & CC) as a result of reasons mentioned above.

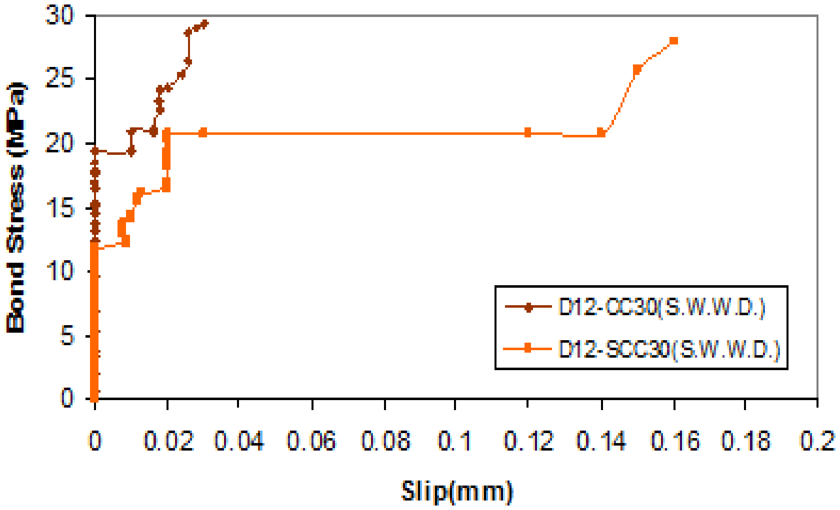

Figure12.Comparison between Bond Stress of SCC and CC (S.W.W.D.) for Compressive Strength of 30 MPa and Bar Diameter of 12 mm.

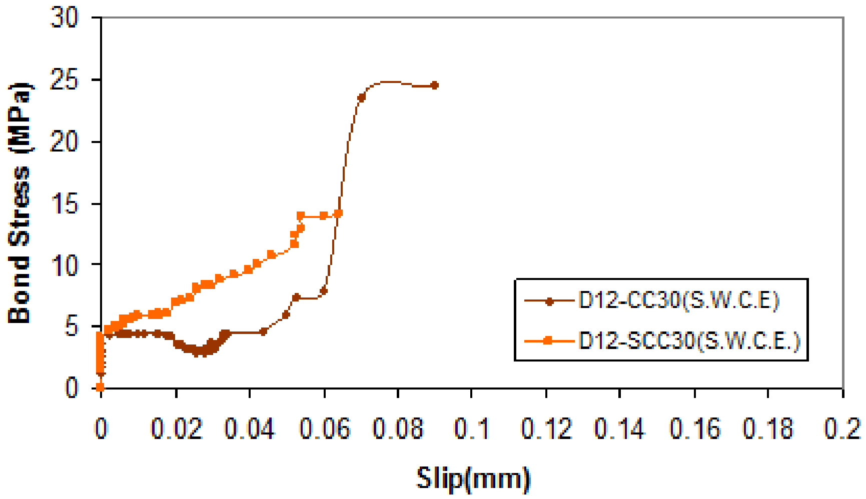

Figure13. Comparison between Bond Stress of SCC and CC (S.W.C.E.) for Compressive Strength of 30 MPa and Bar Diameter of 12 mm.

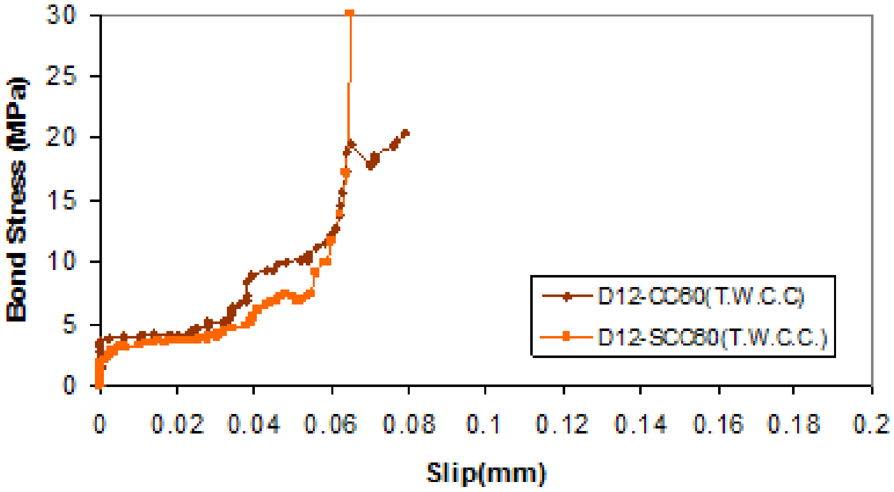

Figure14. Comparison between Bond Stress of SCC and CC (T.W.C.C.) for Compressive Strength of 60 MPa and Bar Diameter of 12 mm.

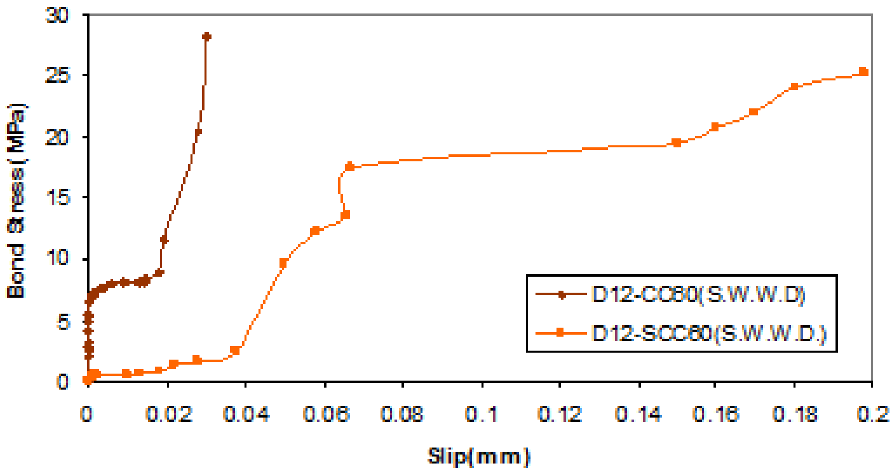

Figure15. Comparison between Bond Stress of SCC and CC (S.W.W.D.) for Compressive Strength of 60 MPa and Bar Diameter of 12 mm.

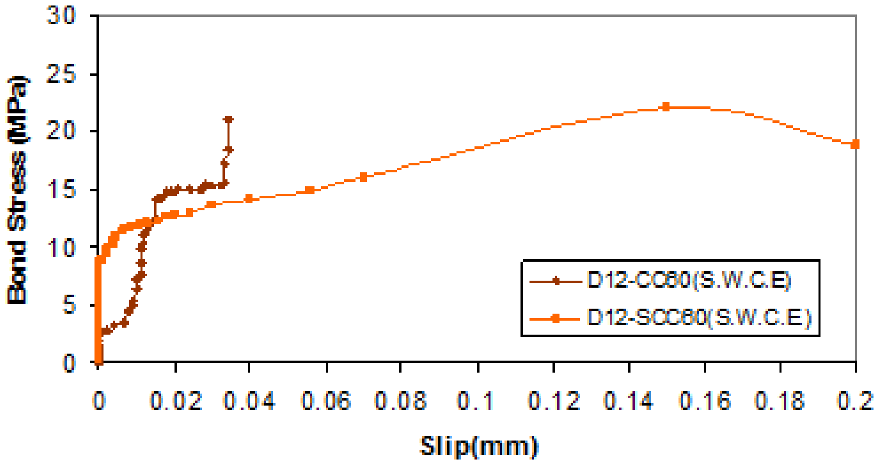

Figure 16. Comparison between Bond Stress of SCC and CC (S.W.C.E.) for Compressive Strength 60 MPa and Bar Diameter 12 mm.

5. Conclusions

Depending on the test results of this study, the following conclusions are obtained:

1. In this work, it is possible to proportion SCC with a specified compressive strength 30, 60 MPa.
2. The experimental fresh properties results for slump flow are between (635-700) mm, which an acceptable.
3. The experimental fresh properties results for L-box are between (0.86-0.94), thus the two mixes have acceptable values of the passing ability ratio.
4. Bond strength increases by decreasing the bar diameter. The bond strength for a bar diameter of 8 mm is greater than that for a bar diameter (12 and 16) mm for SCC (30,60)MPa and curing type saline water wetting and drying (S.W.W.W.), saline water continues (S.W.C.E.).
5. The experimental results of the bond stress and the corresponding slip for the same steel bar diameter and different concrete compressive strengths (30,60 MPa), the increase of compressive strength of concrete causes an increase in the bond strength between the concrete and the steel bar in case of tap water continuous curing and saline water continuous exposing, but in case of saline water wetting and drying curing, the increase in compressive strength of concrete, the bond strength between the concrete and the steel bar decrease because the type of curing. Curing can be defined as a procedure for insuring the hydration of the cement. The hydration of cement is the chemical reaction between grains of cement and water to form the hydration product, cement gel (82) .

The decrease in compressive and bond strength is caused by the defect of hydration.

6. It is noticed that, all beam specimens fail by flexural and shear failure except five beam specimens (A2-30, A4-30, C1-30, and C3-60) which show pull out failure.
7. Results of the dry bulk density, for both types of concrete (SCC and CC) show that the gain of dry bulk density of SCC is slightly higher than those of the CC. The test results show that, the dry density increases with time of curing, for both types of concrete (SCC and CC) T.W.C.C.)). The dry densities of both types of concrete

are close to each other but there are some differences in values of dry densities from specimens exposure to saline water (continuous exposing & wetting and drying curing) which results show decrease in density with time of curing, for both types of concrete (SCC and CC).

8. The results of comparison between all specimens of SCC and CC bond stress-slip relationships show that, the CC bond strength is lower than the SCC bond strength in two cases of curing (tap water continuous, saline water continuous exposing), but in case of saline water wetting and drying exposing, the CC bond strength is higher than SCC bond strength.
9. The theoretical results of comparison between pull-out and beam specimens of SCC and CC ultimate bond stress show that the CC ultimate bond strength (18.4 MPa) is higher than the SCC ultimate bond strength (17.9 MPa) of pull-out specimens (17). In beam specimens CC, ultimate bond stress shows that the CC ultimate bond strength (17.8 MPa) is lower than the SCC ultimate bond strength (30.1 MPa) (in same compressive strength 60 MPa and bar diameter 12mm .

6. Notation

BR	The blocking ratio
C	Concrete cover to reinforcement (mm)
c	Clear spacing between reinforcement
CC	Conventional concrete
d_b	Nominal bar diameter(mm)
f_{cm}	The uniaxial concrete compression strength
fs	Tensile stress in reinforcing bar (MPa)
f_{cu}	Concrete compressive strength (MPa)
HWRA	High water reducing agent
L_b	Embedment length (mm)
ls	Bonded length(mm)
LSP	Limestone powder
P	The applied load
S	Slip (mm)
SCC	Self compacting concrete
SCCC	Self compacting concrete civil engineering
SCCH	Self compacting concrete housing
SF	Slump flow (mm)
sp	Superplasticizer
U	Bond strength (MPa)
Vt	Total volume of the concrete mix
W	Water
Φ	Bar diameter
ACI	American Concrete Institute
ASTM	The American Society for Testing and Materials
EFNARC	The European federation dedicated to specialist construction chemicals and concrete systems.
I.Q.S	The Iraqi standards

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