THE EFFECTIVE EMBEDDED LENGTH OF STEEL BARS IN SELF COMPACTED CONCRETE (SCC)

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ABSTRACT:

Eight reinforced concrete beams were tested in order to investigate the effective embedded length of the longitudinal reinforcement bar in self compacted concrete (SCC). All specimens were reinforced with a uni-reinforced bar, six of them embedded in self compacted concrete and the others embedded in normal concrete. The test was carried out on simply supported beams loaded at two points. At the end of the reinforcement bar slip was measured, also under the loading point slip and the bar strain were measured. The investigated variables in this study were: **The bar diameter,** and **the available embedded length**.
To find out how these variables influence the embedded length in case of using self compacted concrete and comparing it with the normal concrete.
The results show that, with increasing the bar diameter, bond stress slightly decreases, while with increasing the embedded length of the longitudinal bar the bond stress decreases and this improves the mode of the bond failure, especially for the specimens having small bar diameter.

Key word: SCC, Bond strength, Bond stress, Embedded length and Shear span**.**

الخلاصة:

دراسة عملية اجريت على ثمان عتبات خرسانية مسلحة لدراسة الطول المطمور لقضبان حديد التسليح الموضوع في الخرسانة ذاتية الرص . كل التماذج تحتوي على قضيب تسليح احادي . ست منها استعملت فيها خرسانة ذاتية الرص ونموذجين استعمل فيها الخرسانة الاعتيادية. الفحوصات اجريت على عتبات بسيطة الاسناد، حملت بنقطتي تحميل. في نهاية حديد التسليح تم قياس الانسحاب ، واسفل نقطة التحميل تم قياس الانسحاب لحديد التسليح مع الانفعال الحاصل في حديد التسليح.
تم بحث المتغيرات التالية في هذه الدراسة: **قطر قضيب حديد التسليح. وطول التثبيت المتاح لقضبان التسليح.**
لايجاد كيفية تاثيرهما على قيم الطول المطمور في حالة استخدام خرسانة ذاتية الرص ومقارنتها بالخرسانة الاعتيادية.
اظهرت النتائج المختبرية بانه مع ازدياد قطر حديد التسليح يقل اجهاد الترابط بمقدار طفيف. ومع ازدياد الطول المطمور يقل اجهاد الترابط وهذا يحسن من نوع فشل الترابط الحاصل، وخصوصا في النماذج الحاوية على تسليح قليل.

INTRODUCTION:

Most of the researchers investigated the bond strength tests in normal or high strength concrete. All of them were concurrent in the factors that affective on the bond strength. [Ferguson et al 1954] studied the effect of concrete cover on bond strength of reinforcement. [Hribarand and Vasco1969] investigated the end anchorage and its effect on the pull out of the main reinforcement. [Lutz 1970] studied the effect of transverse reinforcement (stirrups) on bond strength, he found that, when using stirrups improve the bond strength.

Many techniques of tests were used to find the bond strength. Some researchers used the direct pull out test [Watstein 1947 and Tepfers 1973]. Others used beams technique [Ferguson et al 1954 and Ferguson 1965]. Also Eccentric pull out specimen technique were used [Ferguson1965] to simulate the actual behavior of reinforcing bars in concrete beam. Few tests were made on bond strength of self compacted concrete (SCC). [Sonebi et al 2000] and [Foroughi et al 2008] studied the bond strength by using pull-out tests on bars embedded in SCC.

Mechanism of failure:

The applied external load resisted by an internal force couple in simply supported beam, represented by the top compression force in concrete and the tensile force in steel reinforcement. The equation $dM/dX = V$ means that if there is any change in moment with respect to the beam length shear force will appear. This can happen in shear span. Where there is a variation in applied moment from maximum value at applied load to zero value at support, resulting longitudinal shear force on reinforcing bars. This shear force leads to cause shear cracks which has a bad effects on bond strength, as shown in **Fig (1)**, this can be explained as follows [Stratford, and Burgoyne 2003]: when the shear cracks appear the longitudinal reinforcement act as a dowels and by increasing the shear force (applied load) the shear cracks propagate toward the support around the longitudinal reinforcement and the bond failure will occur by splitting the concrete in this region. So, the mechanism of bond failure is not due to pure of pull out the main reinforcement due to axial force only, but due a combination of loads which cause bond failure.

Many researches on bond strength were carried out by applying pure axial tensile force, by pulling out a reinforcement bar from a concrete block. In pull out technique the tensile stresses in the reinforcement bar are transmitted progressively from the point of applied loading throughout the reinforcement bar and by shear stress to the concrete surrounding the reinforcement bar to the concrete block. The failure will beginning at the concrete surrounding the steel bar near the top of the concrete block surface, as shown in **Fig (2)**. Due to the difference in the deformations of the two materials (steel and concrete) the cracks will start to appear at the top zone of the concrete block. Then the maximum tensile stress in the steel bar will transmit to the next adjacent part of the bar downward the concrete block. This process makes the bond failure progressive and the bond stresses is not constant along the overall embedded length (the embedded length not works together). Rather than, the manner of applying load in the pull out test makes the top concrete block surface compress and the relative slippage between the reinforcement bar and the concrete top surface will deviate slightly from the real value. In contrast [Orangen et al 1975] assume that the bond stress was constant along the bar reinforcement.

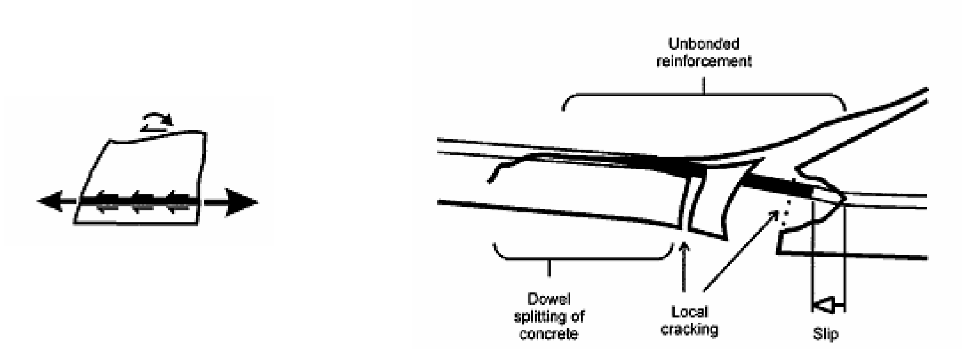

Figure (1): Beam with no shear reinforcement [Stratford and Burgoyne 2003]

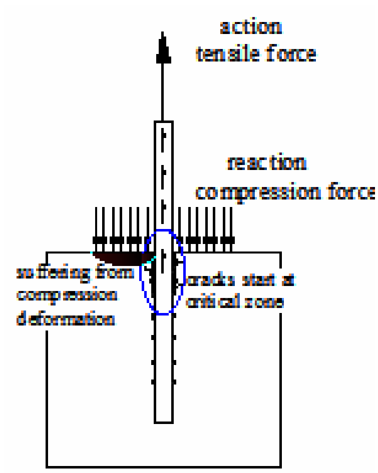

Figure (2): Mechanism failure of the pull-out test

MATERIAL PROPERTIES:

The cement used in this study was Ordinary Portland Cement complying with ASTM C150-02. The test results are shown in **Tables (1 & 2)**

Table (1): Chemical cement test results

Chemical composion	
Composition	Quantity%
SO_3	1.24
MgO	2.80
C_3A	8.60
SIO_2	21.2
Al_2O_3	5.4
L.O.I	3.34
C_3S	35.1
CaO	52.5

*Chemical analysis was conducted by National Center for Construction Laboratories and Researches

Table (2): physical cement test results

Physical properties	
Compressive strength, MPa (3 days) (7 days)	 32.6 39.4
Setting time (Vicate apparatus), Initial setting, h:min Final setting, h:min	 2:35 4:40
Specific surface area (Blaine method), m^2/kg	472
Soundness (Auto Clave) method, %	0.24

*Physical tests was conducted by National Center for Construction Laboratories and Researches

The coarse aggregate used was natural aggregate with nominal size 4.74-19mm. The grading obtained from the results of sieve analysis of the aggregate lies within the range defined by ASTM C136-01.

The results of the sieve analysis which was carried out on fine aggregate lies within the range defined by ASTM C136-01. The chemical and physical test results for gravel and sand are shown in **Tables (3 & 4)** respectively.

Table (3): Chemical and physical test results of gravel

properties	Test results
Absorption %	0.70
Specific gravity	2.60
Dry loose-unit weight kg/m^3	1582
Sulfate content as SO_3 %	0.42
Materials finer than 75µm%	2.80

- Tests was conducted by National Center for Construction Laboratories and Researches

Table (4): Chemical and physical test results of sand

properties	Test results
Absorption %	0.54
Specific gravity	2.54
Sulfate content	0.07

- Tests was conducted by National Center for Construction Laboratories and Researches

Glenium 51: (modified polycarboxylic ether) was used as a water reducing agent plus a stabilizing agent with a specific gravity of 1.1 at 20^{o}C, PH = 6.5 as issued by the producer.
Silica fume mineral admixture or micro silica: composed of ultrafine, amorphous glassy spheres of silicon dioxide (SiO_2), produced by Warrington, England, Crosfield Chemicals.

CONCRETE MIX PROPORTIONS:

Several trail mixes were used. The final mix proportions used was 1:1.5:1.6 by weight with water cement ratio 0.5 plus 3 liters of glenium-51 admixture for each 100kg of cement. The mixture proportions are summarized in **Table (5)** below.
The slump flow for the self compacted concrete was 710mm (using cone test-ASTM C1611-05) and the slump test for the normal concrete was 110mm (ASTM C143-00).
The longitudinal steel reinforcement bars were deformed. Determine their tensile properties according to ASTM 615-05a. The results are shown in **Table (6)**.
The mixing of concrete was carried out in a tilting pan type mixer of 0.1m^3 capacity. In all the mixes, the aggregates and cement were first mixed dry for about 90 seconds. The water, silica fume and the superplasticizer together were mixed externally in a pan then were added to the pan mixer, after that mixing continued, for a further 90seconds.
With each beam the following specimens were cast to determine the properties of the hardened concrete:

3-150mm diam. x 300mm long cylinders for compressive strength.

3-150mm diam. x 300mm long cylinders for indirect tensile strength.

Table (5): Concrete mix proportions

		SCC	NC
Water	Kg/m^3	200	200
Super plasticizer	lit./100Kg (powder)	3	-
Cement	Kg/m^3	392	400
Silica Fume	Kg/m^3	8	-
Total Powder (Cement+ Silica Fume)	Kg/m3	400	400
Gravel	Kg/m3	640	640
Sand	Kg/m3	600	600

Table (6): Properties of steel bars

Bar diameter (mm)	Modulus of elasticity (GPa)	Yield stress (MPa)	Strain at yield stress (microstrain)	Ultimate stress (MPa)
6	201	510	2537	650
12	198	500	2525	630
16	199	480	2412	580

EXPERIMENTAL PROGRAM:

Eight beams were tested as simply supported beams. The clear span was 1000mm. All beams have the same dimensions; 100mm wide and 180mm deep as shown in **Fig (3)**. Load was applied by using hydraulic jack. **Table (7)** shows the details of the beam specimens.

The bar embedded length was specified as follows: grooves were made by using filler material (cork) placed and fixed to the mold and tied to the reinforcement bar at the inner side of the shear span of the beam under the loading point. The other end of the embedded length (the free end) was rolled up by a tephlon as a spreader between the concrete and the reinforcement bar.

The slip at the free end of the reinforcement bar, is called free end slip (slip at the end of the embedded bar), as shown in the **Fig (3)**. This slip was measured by using a dial gage fixed on a steel angle glued on the beam end.

At the groove (under the applied load), the loaded end slip which is the relative slippage between the reinforcement and the concrete of the groove side was measured, as shown in **Fig(3)**, by welding a 6mm bar diameter with 30mm long to the reinforcement bar side to fix the dial gauge. On the other side of the reinforcement bar at the groove zone two bars 6mm diameter with 30mm long welded at a space of 50mm to gluing the demec discs to measure the strain in the reinforcement bar by using the demec gauge.

All dial gauges were used to measure the slip have sensitivity of 0.002mm/division. The details of the beam reinforcement, all dimensions and details of fixing the test instruments were used are shown in **Fig (3)**. **Fig (4)** shows the beam was tested in a rig using a machine 25tons loading capacity.

Table (7): Details of the bar diameter with the embedded length

Beam designation	Bar diameter (mm)	Embedded length (mm)	Type of concrete
B1	12	150	SCC
B2	12	200	SCC
B3	12	250	SCC
B4	16	150	SCC
B5	16	200	SCC
B6	16	250	SCC
B7	12	250	NC
B8	16	250	C

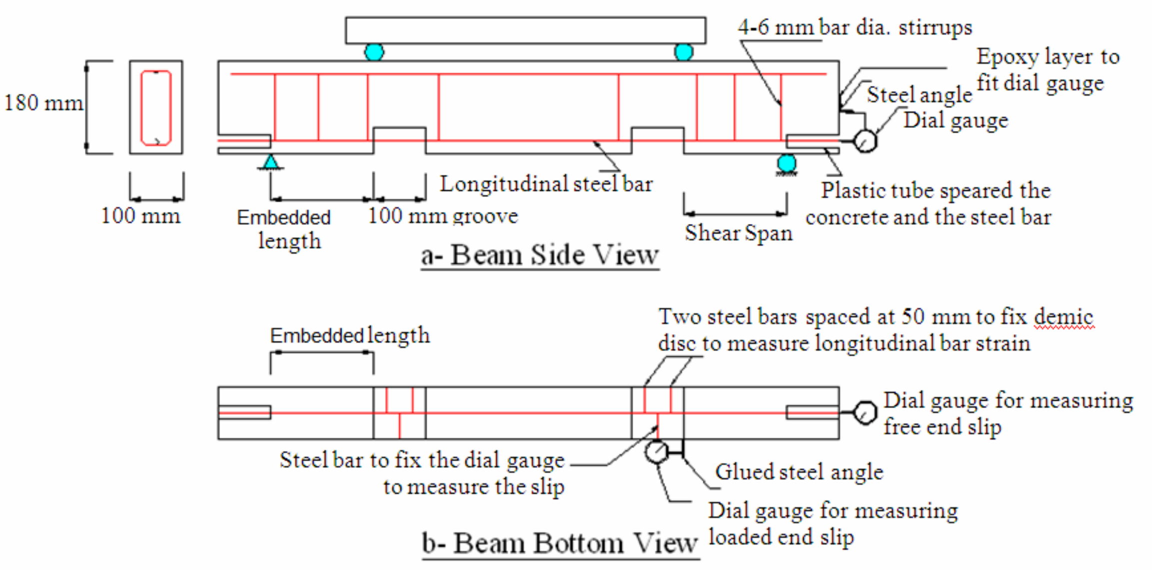

Figure (3): Details of the beam specimens

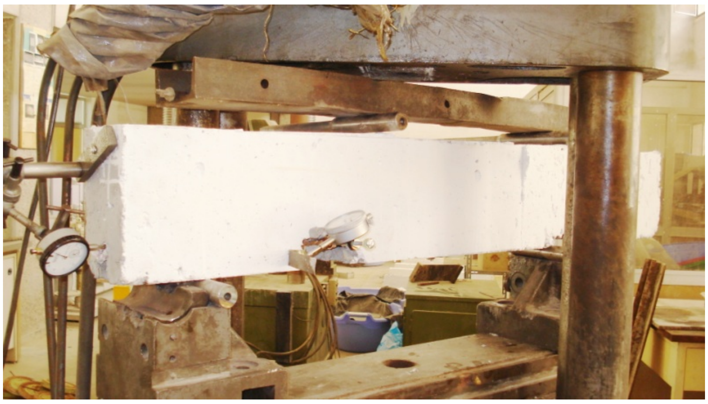

Figure (4): Test set up of beam B3

RESULTS AND DISCUSSION:

Mode of failure**:** All beams failed by the splitting of the concrete cover in the anchorage zone (along the embedded length or the bottom face of the shear span). As shown in **Table (8)**, three beams failed in bond after yielding of the bar reinforcement and the other five beams failed by splitting of the concrete cover before yielding of the bar reinforcement. Also, it shows that increasing the embedded length; improve the mode of failure, by delaying the pull out of the reinforcement bar and splitting of the concrete cover until the stress in the reinforcing bar reach the yielding stress. This improvement was more than that in beams with smaller bar diameter than that of larger bar diameter. Where, for the beams with 12 mm bar diameter, increasing the embedded length 33% gives improvement in the mode of bond failure, while for beams with 16mm bar diameter, similar improvement requires 66% increasing in the embedded length.

The cracks pattern development were as follow**:** at the bottom face of the beam shear span, a longitudinal splitting crack started to appear from the loaded point at the end face of the groove and developed toward the free end of the beam, along the bar reinforcement, as shown in **Fig (5)**. At the same region, with increasing the applied load flexural crack was observed (transverse crack) at a right angle to the longitudinal bar. With more applied load this main longitudinal crack gradually increased till reaching the free end of the beam, at the same time and with increasing applied load many flexural cracks were appeared and some of them changed to diagonal tension cracks to joining the flexural cracks until the concrete cover at the anchorage zone was marked with one main longitudinal splitting crack and many transverse flexural and diagonal cracks, causing bond failure. In the same time at the mid span zone many flexural cracks were observed. In spite of the beams containing shear reinforcement, but at the two side faces of the shear span some diagonal shear cracks were observed, gradually growing and propagated toward the loading point, but no shear failure were happened.

By equating the tensile force on the bar with the total bond force on the bar surface area $l_d \ \pi \ d_b \ u = A_b \ f_s$ bond stress can be found $u = \dfrac{d_b \ f_s}{4 \ l_d}$, as shown in **Table (8)**, where the bar stress can be measured experimentally by measuring the strain at the groove zone. In this equation the quantity $d_b/4$ is constant for each group of beams (B1, B2 and B3) and (B4, B5 and B6), so, the calculated bond stress u will depends on f_s/l_d , this value decrease with increasing the embedded length, because the increase in the reinforcement stress less than that of the embedded length. This means with increasing the embedded length the bond stress will decrease; despite of that, the bond failure was observed, because this equation assume that the bond stress is constant along the embedded length, while the value f_s is measured under the loading point at the inner end of the shear span (embedded length) only and it is not constant along the embedded length. So, the value of the bond stress u which causes the failure is higher than the calculated value, because the failure is progressively propagated process, and it is not constant along the embedded length.

Table (9) shows the loaded and free ends slip of the reinforcement bar near failure. The loaded end slip is higher than that of the free end slip for all beams, this because, the cracks started to appear from the groove zone and developed to the next adjacent region toward the beam end. So, the bond failure (separation) between the concrete and the reinforcement bar started from the groove zone propagated toward the beam end (free end). **Fig (6)** shows the difference between free end slip and the loaded end slip for beam B2 at different bond stress. At the earlier loading stage the bar reinforcement slip at both loaded end and the free end no slip were recorded. With increasing applied load the loaded end started to record slip while the dial gauge at free end slip was not sensitive any slip. After that, with increasing the applied load the loaded end slip increased more than that of the free end slip. Near the bond failure the slip of the loaded end was 5 times that of the free end of the reinforcement bar. In **Fig (6)**, the difference in behavior proves that, the bond stress is not constant and the bond failure is progressively process. Also, **Table (9)** shows with increasing the embedded length the loaded end slip increase while the free end slip decrease. Because increasing the embedded length will delay the pull out of the reinforcement bar and allowing to more slipping at the groove zone, but for each bar diameter the ratio of loaded end slip /embedded length is approximately similar, this means that increasing the embedded will increase the loaded end slip in approximately same quantity, despite of that, the mode of bond failure changed, if the bar diameter is constant. This means the loaded end slip has fewer effects on the bond failure. Also **Fig (7)** shows, with increasing the embedded length the loaded end slip increase, while Fig (8) shows less difference between the loaded end slip with increasing the embedded length, due to increasing in bar diameter. **Fig (9)** shows, with increasing in bar diameter the loaded end slip will decrease, because the stresses in the bar will decrease, or the bond stress will decrease. Same observation was recorded by [Sonebi et al 2000], and by [Ferguson et al 1954] but comparing the SCC beams with that which used normal concrete (NC) as shown in **Figs (7&8)**, the deference were very clearly in the bond stresses and the slip at both loaded and free end slip, this because of the enhancing the concrete properties such as the compressive strength and the concrete tensile strength which is affect on the bond strength. But, [Mindess et al 2003] they show that the compressive strength increases more than that the tensile strength.

The bond failure is specified by the free end slip, because it is the last resistance point of the embedded length. **Figs (10 & 11)** show the free end slip-bond stress curves for beams containing 12mm bar diameter and 16mm bar diameter respectively. These figures show that, with increasing embedded length the free end slip will slightly decrease, as mentioned previously the bond stress is not uniform along the embedded length. So, the bond stress which causes the slip at the free end is less than that at the loaded end. **Table (9)** shows, increasing the embedded length will decrease the free end slip of the reinforcement bar, where, increasing the embedded length by 33% and 25% give decrease in free end slip about 14% and 26% respectively for beams with longitudinal bar diameter 12mm, and 28% and 9% for bar diameter 16mm respectively. **Fig (12)** shows, with increasing bar size the free end slip will increase, and the curves of the NC beams tend to be more flattened than the curves of the SCC beams, this because of the improvement of concrete properties. **Fig (13)** shows, with increasing the embedded length, the ratio of free end slip/embedded length decreases (for each similar bar diameter group), and the curves tend to be horizontally with increasing the embedded length, i.e. excessive increasing in embedded length has no effect on the bond strength. Theoretically if each curve in **Fig (13)** extends to the x-axis (zero end slip) point of intersecting will find the best embedded length. But this curve needs more experimental tests to get an adequate embedded length, for each type of concrete strength and bar diameter. The curve of beams with 16mm bar diameter was above that of 12mm bar diameter, this means increasing bar diameter needs to increase the embedded length. Beams with SCC, increasing the bar diameter by 33% gives increase in the free end slip by 45%, 21% and 50% for beams with 150mm, 200mm and 250mm embedded length respectively, and it was 16% in NC beam.

Table (8): Beams test results.

Beam designation	Embedded length* (mm)	Bar diameter (mm)	Compressive strength (MPa)	Steel stress (MPa)	Bond stress (MPa)	Mode of failure
B1	150	12	43	484	9.68	Bond
B2	195	12	45	535	8.23	Bond with yield
B3	245	12	44	610	7.47	Bond with yield
B4	150	16	45	362	9.25	Bond
B5	200	16	42	416	8.02	Bond
B6	255	16	44	485	7.61	Bond with yield
B7	250	12	27	354	4.25	Bond
B8	255	16	26	257	4.03	Bond

*Embedded length is for the failed side of concrete beam.

Table (9): results of loaded end and free end slips

Beam designation	Loaded end slip		Free end slip (mm)	
	slip (mm)	Slip/embedded length x 10^{-3}	Slip (mm)	Slip/embedded length x 10^{-3}
B1	0.87	5.8	0.22	1.47
B2	1.12	5.7	0.19	0.97
B3	1.49	6.08	0.14	0.57
B4	0.51	3.4	0.32	2.13
B5	0.59	2.95	0.23	1.15
B6	0.63	2.47	0.21	0.82
B7	0.42	1.68	0.53	2.12
B8	0.37	1.45	0.62	2.43

Figure (5): Crack pattern of beam B3 after failure

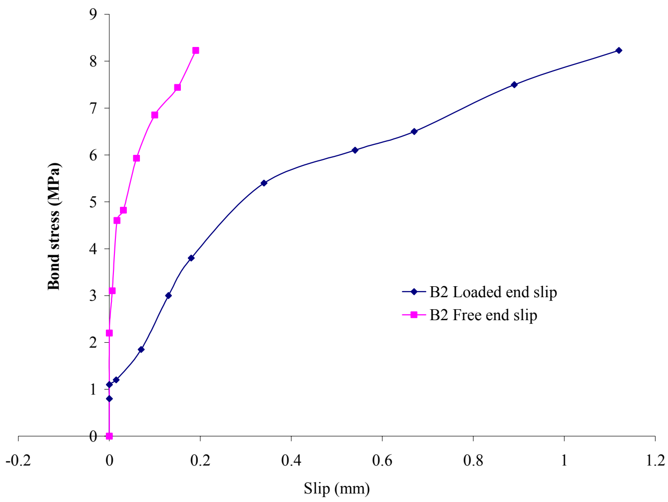

Figure (6): Bond stress versus loaded slip and free end slip for beam B2

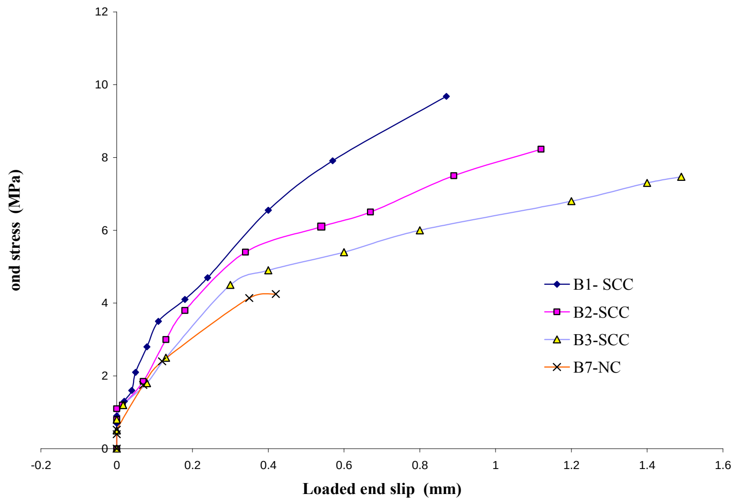

Figure (7): Bond stress versus loaded end slip for beams with 12mm bar diameter

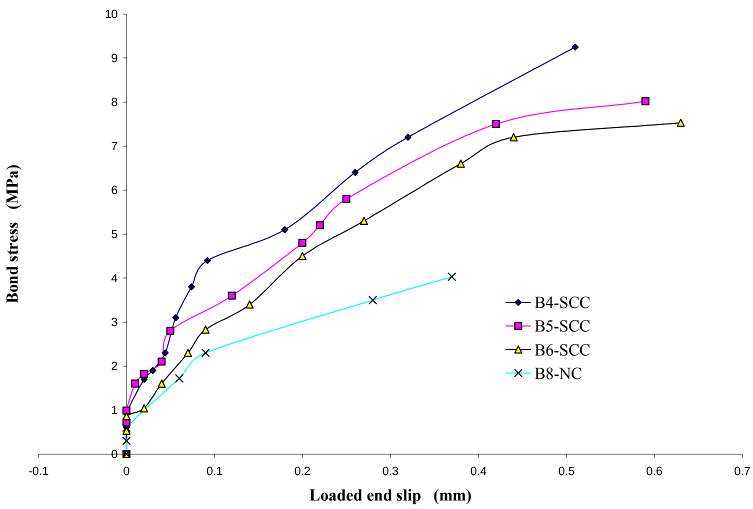

Figure (8): Bond stress versus loaded end slip for beams with 16mm bar diameter

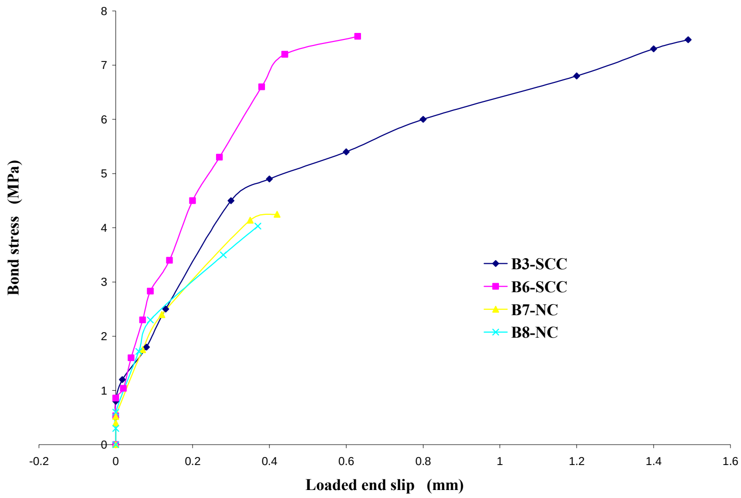

Figure (9): Bond stress versus loaded end slip for beams had same embedded length and different bar diameter

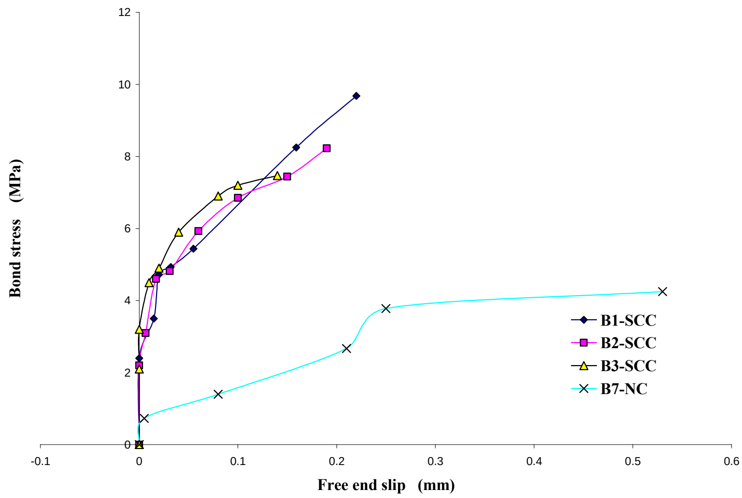

Figure (10): Bond stress versus free end slip for beams with 12mm bar diameter

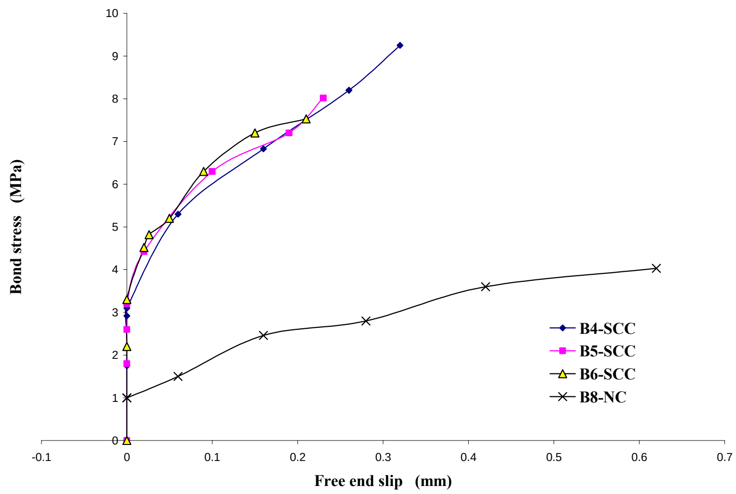

Figure (11): Bond stress versus free end slip for beams with 16mm bar diameter

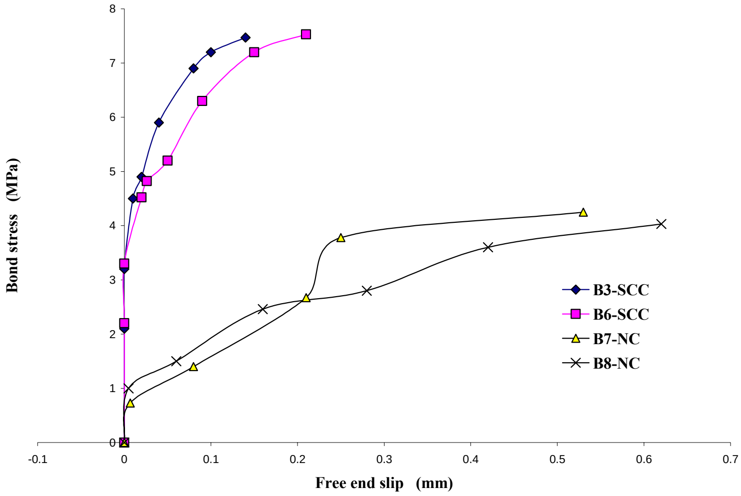

Figure (12): Bond stress versus free end slip for beams had same embedded length and different bar diameter

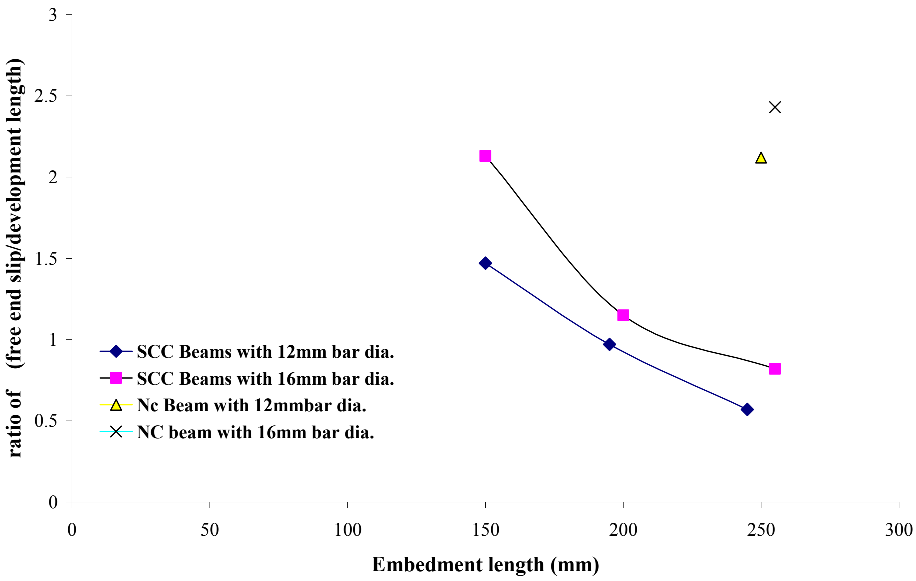

Figure (13): The ratio of $\left(\frac{free \quad end \quad slip}{loaded \quad end \quad slip}\right)$ **versus with the embedded length**

CONCLUSION:

1- Using self compacted concrete enhancing the concrete properties (compressive strength and tensile strength), which affects on bond strength of the bar embedded on it.
2- The bond stress is not constant along the embedded length of the reinforcement bar. It reaches the maximum value under the loading point and decreases toward the embedded length end (beam end).
3- Increasing embedded length 33% for beams with 12mm bar diameter give improvement in the mode of bond failure, while for beams with 16mm bar diameter similar improvement requires 66% increasing in the embedded length.
4- Free end slip of the reinforcement bar, specify the bond failure, which affected by the embedded length and the bar diameter.
5- Increasing the embedded length will decrease the free end slip of the reinforcement bar, where increasing the embedded length 33% and 25% give decrease in free end slip about 14% and 26% respectively for beams with longitudinal bar diameter 12mm, and 28% and 9% for bar diameter 16mm respectively.
6- Increasing bar diameter will increase the free end slip. The 33% increase in bar diameter gives 50% increase in free end slip for SCC beams and 16% for NC beams
7- With increasing the longitudinal bar diameter, embedded length needs increasing.
8- The relation curve of embedded length versus ratio of free end slip/embedded length shows a good relationship between the variables studded in this research.

NOTATIONS:

A : Bar cross-section area (mm^2)

d_b : Bar diameter (mm)

l_d : Actual embedded length measured from the groove at the loaded end to the free end as shown in Fig (3-a) (mm).

f_s : Steel stress (MPa)

NC: Normal concrete.

SCC: Self compacted concrete

u : Bond stress (MPa)

$\left(\frac{dM}{dx}\right)=V$ **:** Change in moment with respect to beam length causes shear force

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