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

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ABSTRACT:

Experimental research was carried out on eight reinforced concrete beams to study the embedded length of the longitudinal reinforcement. Six beams were casted using self compacted concrete, and the two other beams were casted using normal concrete. The test was carried out on beams subjected to two point loads. The strain and the slip of the main reinforcement have been measured by using grooves placed during casting the beams at certain places. The measured strain used to calculate the longitudinal stresses (bond stress) surrounding the bar reinforcement,

The study was investigated the using of self compacted concrete SCC on the embedded length of reinforcing bars, and comparing the results with normal concrete.

The test results show that using SCC improve the concrete properties like the compressive strength and the tensile strength which mainly affected the bond strength and the splitting of the concrete cover failure. The testes show that with increasing concrete strength the bond strength increased.

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

الخلاصة:

دراسة عملية اجريت على ثمان عتبات خرسانية مسلحة لدراسة طول الطمر لقضبان حديد التسليح الموضوع في الخرسانة. ست نماذج استخدمت فيها الخرسانة ذاتية الرص ونموذجان استخدم فيهما خرسانة اعتيادية. الفحوصات اجريت على عتبات حملت بنقطتي تحميل. وباستخدام فراغات معينة وضعت في اثناء الصب داخل النماذج لقياس الانفعالات في قضبان حديد التسليح وكذلك لقياس الانزلاق الذي من الممكن ان يحدث، تم قياس اجهاد القص المحيط بقضبان حديد التسليح والمسبب للفشل وانسحاب قضبان حديد التسليح. الدراسة ركزت على عاملين رئيسيين هما:

- قوة تحمل الخرسانة.
- وطول الطمر المتاح لقضبان حديد التسليح.

لايجاد كيفية تاثيرهما على قيم اطوال الطمر في حالة استخدام خرسانة ذاتية الرص. وكذلك مقارنة النتائج مع الخرسانة الاعتيادية. اظهرت النتائج تحسن في خواص الخرسانة في حالة استخدام الخرسانة ذاتية الرص من ناحية مقاومة الانضغاط ومقاومة الشد الذي يؤثر تاثير مباشر على مقاومة الترابط وفشل الغطاء الخرساني وتهشمه.

INTRODUCTION:

The relationship between the workability of concrete against the stability of concrete matrix is specifying the durability and strength of concrete, because the loss of stability will lead to developing cracks in the concrete, which will increase the bond failure between the concrete contents [Foroughi et al 2008].

The self compacted concrete SCC has a high workability with acceptable stability, because the properties of concrete are affected by cementations matrix, aggregate and the transition zone between these two phases. Reducing the water cement (w/c) ratio and the addition of pozzolanic admixtures like silica fume are often used to modify the microstructure of the matrix and to optimize the transition zone [Caijin and Yanzahong 2005]. The reduction of the w/c ratio results in a decrease in porosity and refinement of capillary pores in a matrix. On the other hand, reducing w/c ratio may negatively influence the flowing ability of the fresh concrete, so a high range water reducing admixture must be used to keep an acceptable flowing ability. The effect of the pozzolanic admixtures can be explained by their pozzolanic reaction with calcium hydroxide released from cement hydration and by their filling effect in the voids among cement or other powder materials particles [Timo 2003].

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** and **2** for the chemical and physical properties respectively.
- The coarse aggregate used was natural aggregate with 4.74-19mm nominal size of aggregate. The grading obtained from the results of sieve analysis of the aggregate lies within the range defined by ASTM C33-03.
- The results of the sieve analysis which was carried out on fine aggregate lies also within the range defined by ASTM C33-03. The chemical and physical test results for gravel and sand are shown in **Tables 3** and **4** respectively.
- Glenium 51: (modified polycarboxylic ether) was used as a water reducing agent plus 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 Crosfield Chemicals, Warrington, England,

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CONCRETE MIX PROPERTIES:

Several trial mixes were used. The final mix proportions used is 1:1.5:1.6 with various water cement ratio, the amount of glenium-51 admixture for each 100kg of cement and the content of silica fume. The mixture proportions are summarized in **Table 5**.

The slump flow test was carried out to measure the flowability of the SCC concrete mixes, while the ordinary slump test was carried out in case of using ordinary concrete.

The longitudinal steel reinforcement bars were deformed. Their tensile properties were determined according to ASTM 615-05a. The results are shown in **Table 6**

Table (1): Chemical cement test results

Chemical composition	
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

Table (3): Chemical and physical gravel test results

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 sand test results.

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

Table (5): Concrete mix proportions

Beam designation	B1 & B2	B3 & B4	B5 & B6	B7 & B8
Water / powder (W/P)	0.6	0.5	0.4	0.5
Water Kg/m^3	240	200	160	200
Superplasticizer lit./100Kg(powder)	2	3	4	-
Cement Kg/m^3	392	392	392	400
Silica Fume Kg/m^3	8	8	8	-
Total Powder Kg/m3	400	400	400	400
Gravel Kg/m3	640	640	640	640
Sand Kg/m3	600	600	600	600
Slump flow (mm)	720	705	695	120*

* Slump test

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	195	510	2615	650
16	192	480	2500	580

Mixing of concrete was carried out in a tilting pan type mixer. Aggregates and cement were first mixed dry for about 90seconds, 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.

For each test 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.

EXPERIMENTAL PROGRAM:

Eight simply supported beams were tested; with clear span of 1000mm. Each beam is 100mm wide and 180mm depth as shown in **Fig. 1**. The main variables were the concrete strength and the embedment length, as shown in **Table 7**. Load was applied by using electric hydraulic jack.

Slip of reinforcing bar at the end of concrete beam has been measured by fixing a small steel angle at the face of each free end of the beam to support a dial gage of 0.002mm/div sensitivity, as shown in **Fig. 1b** (this called free end slip).

To specify the free end of the embedded length the bar was wrapped by a thick strip of an adhesive tape as tube spreader between the concrete and bar surface and at the other end of the shear span, groove was made by using pieces of cork placed at the mold and tied by the longitudinal bar.

In the groove zone, a 6mm bar diameter and 30mm long was welded on the longitudinal reinforcement before casting the concrete to fix the dial gage which was 0.002mm/div. sensitivity, and by fixing piece of steel plate at the face of the groove side toward the shear span, the slip under point load was measured, (this called loaded end slip) as shown in **Fig. 1b**. On the other side of the longitudinal bar reinforcement at the groove zone, two bars of 12mm diameter were welded at a space of 50mm, before casting the concrete, to fix the demec discs, to measure the strain in the longitudinal bar reinforcement by using the extensometer with 0.002mm/div. sensitivity. **Fig. 2** shows test set up of beam B1.

Table (7): Details of the beams specimens

Beam designation	Concrete strength	Bar diameter	Embedded length	Type of concrete*
B1	32	16	200	SCC
B2	30	16	250	SCC
B3	43	16	200	SCC
B4	45	16	250	SCC
B5	51	16	200	SCC
B6	53	16	250	SCC
B7	26	16	200	NC
B8	27	16	250	NC

- SCC: self compacted concrete
- . NC: normal concrete

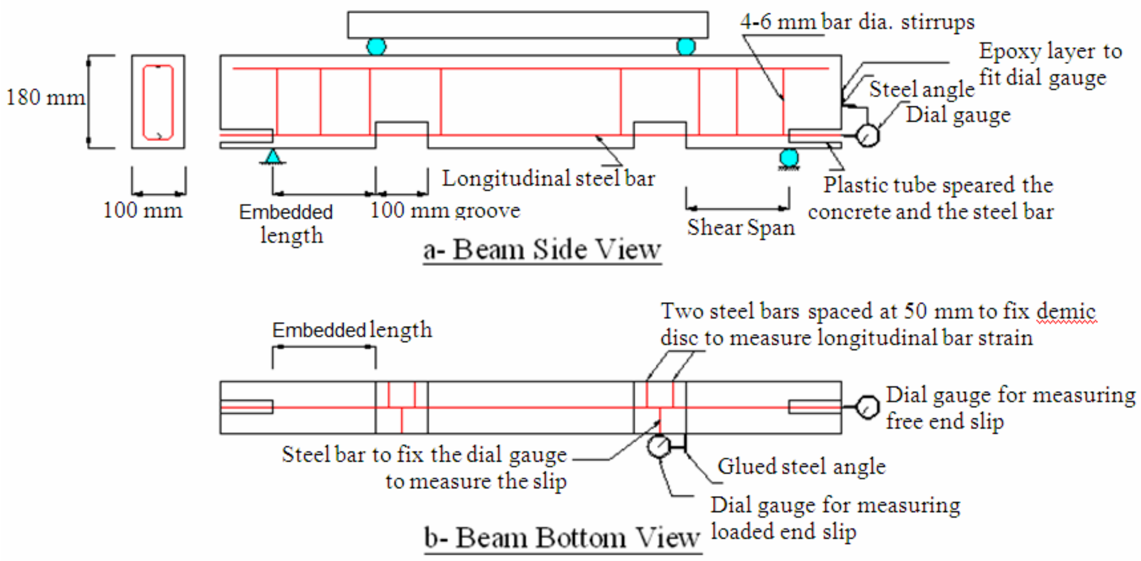

Figure (1): Details of the beam specimens

Figure (2): Test set up of beam B1

RESULTS AND DISCUSSIONS:

Some researchers define the bond strength failure as bond strength where the slippage at the reinforcement reaches a specific value such as 0.25mm [Foroughi et al 2008] while others define the bond strength failure by the ultimate bond strength (maximum average bond stress) where many cracks will appear and the reinforcement will pull out i.e. separation occurs between the reinforcing bar and the surrounding concrete cover [Ferguson et al 1954]. Obviously using a specific slippage is more conservative or the second one is over estimated.

Bond stress (u) in the test was calculated by using the strain which was measured by the extensometer and converted by using the modulus of elasticity of the reinforcement.

$$l_d \ \pi \ d_b \ u = A_b \ f \Rightarrow$$

$$u = \frac{d_b \ f_s}{4 \ l_d} \qquad \text{Eq (1)}$$

Table 8 shows the steel bar stress near failure, the bond stress and the mode of failure. As shown in this table with increasing compressive strength of the concrete the mode of failure enhancing by delaying the bond failure (splitting of concrete cover) till reaching the reinforcement to the higher stresses (yielding of the reinforcement). Splitting cylinder tension test was carried out by using 300mm x 150mm cylinders to find the concrete tensile strength. Because shear and bond strength are dependent on the tensile strength of the concrete [Holm 1994]. **Table 9** shows the tensile test and the ACI-code equation results. The test results show improvements in the tensile strength in case of using *SCC* as compared to the *NC*. Also, it shows the ratio of splitting tensile strength to compressive strength (f'_{ct} / f'_c) to be ranging from 8 to11, in agreement with [Avram et al 1981]. They found that (f'_{ct} / f'_c) ranges from about 6 to 20. Also the table shows that, the increase in compressive strength is higher than that in the tensile strength. So, the ratio (f'_{ct} / f'_c) approximately deceases with increasing in compressive strength. This observation watches that of [Mindess et al 2003] where they show that as the compressive strength increases the ratio (f'_{ct} / f'_c) decreases. Also, comparing the test results with that of the ACI-code (the ratio of measured /calculated tensile strength) shows that, the ratio was more than one and it increased with increasing the SCC compressive strength i.e. the ACI-code results were underestimated in case of using SCC, in contradict, the ratio was less than one for normal concrete.

Crack patterns: all beams show typical crack patterns. During loading steps, a longitudinal main crack appeared from the groove zone at the beam tension face and extended towards the beam free end. During that with increasing the applied load, transverse cracks were observed and gradually extended upward to the beam sides (in the shear span) and growing diagonally toward the loading point, but the shear reinforcement prevents shear failure. Also, some diagonal cracks were observed at the beam bottom face. These cracks propagated, growing and joining together to cause the splitting of the concrete cover at the beam bottom face. The main difference between the beam crack patterns, were that, with increasing of the compressive strength the transverse cracks were concentrated in a few numbers than that for the beams with less compressive strength, where many cracks were observed. This can be seen in **Fig. 3** and **Fig. 4** for beams B2 and B3 respectively.

Loaded end slip: (the dial gauge under the loading point).

1 - All beams shows that at earlier loading stages, no slip to occur at the loaded end slip (the dial gauge at the groove zone), because the whole concrete section works in both tension and compression together to resist the applied load. When the cracks began to appear at the bottom face of the shear span, slip was recorded. Beams with NC recorded slightly earlier slip than beams with SCC**,** for the similar bond stress, the earlier loaded end slip increased as the concrete strength decrease, and at the latest loading steps it will increase, as shown in **Figs 5** and **6**.

2 - The experimental results in **Figs 7** and **8** show, for the beams of approximately equal concrete strength, the loaded end slip was similar but with slightly differs near failure, with increasing the embedded length by 25% the loaded end slip increased by about 20%. This tendency to occur because the bond failure is progressively starting from the loaded end toward the free end and as the embedded length increased this will delay the bond failure (concrete splitting) and allow to record more loaded end slip. **Table 10** shows the ratio of the loaded end slip of SCC beams to NC beams (which they had same embedded length but with different concrete strength) i.e. beams B1, B2 and B3 to B7 (which they had same l_d = *200mm)* the ratios were 25%, 36% and 157% respectively and for B2, B4 and B6 to B8 (which they had same l_d = *250mm)* the ratios were 18%, 21% and 116% this due to the same reason above (the bond failure is progressively starting from the loaded end toward the free end and as the embedded length increased this will delay the bond failure).

Free end slip: (The last point of the shear span toward the beam end)

1- The free end slip was less than that for loaded end slip at all loading steps, and comparing beams having same embedded length but with different concrete strength as shown in **Figs 9 and 10**, the free end slip decrease with increasing the concrete strength, this because of the enhancing in the concrete properties especially the tensile strength of the concrete (concrete surrounding the reinforcement bar). **Table 10** shows with increasing the compressive strength the free end slip will decreases.

2- **Figs 11** and **12** shows, increasing the embedded length will decrease the free end slip, because the bond stress is not uniformly distributed along the embedded length, its highest value at the loaded end and gradually decreases or vanished near the free end. This was visible in the crack patterns. They were forming and propagating from the loaded end toward the free end during the loading stages, so, the bond failure is progressive process. Many researchers had the same observation and they connect between the bond strength and the square root of the concrete strength [Ferguson 1962], [Untrauer and Henry 1965] and [Kemp and Wilhelm 1997] when the other factors are constant, while [Orangun et al 1975] study the lap splices, they assume that the strain variation along the splice approximately linear.

CONCLUSIONS:

1. Using SCC improves concrete strength (compressive strength and the tensile strength) as a result, resistance of the concrete to prevent pull out the reinforcement bar, compared to the NC, this was observed by enhancing in the mode of failure from bond failure (pull out) to bond with yielding the reinforcement bar.
2. The loaded and free ends slip for the SCC beams were less than that for the beams with NC at the similar loading stag (bond stress).
3. Beams with similar embedded length, increasing the concrete strength will decrease the earlier loaded end slip and increasing the loaded end slip near the failure.
4. While for the similar concrete strength, increasing the embedded length will increase the loaded end slip, and decreasing the free end slip near the failure.
5. The cracks propagates from the loading point extended towered the free end, this means that , the bond stress is not uniformly distributed along the embedded length, it reaches the maximum value at the loading point and decreases or vanished near the free end .
6. The bond failure depends on the free end slip, because it's the last resisting point of the embedded length, and increasing the embedded length will decrease the free end slip or delaying the bond failure.

Table (8): Beams test results.

Beam designation	Embedded Length * (mm)	Compressive strength (MPa)	Steel stress (MPa)	Bond Stress *u* (MPa)	Mode of failure
B1	205	32	337	6.57	Bond
B2	250	30	384	6.14	Bond
B3	204	43	427	8.37	Bond
B4	246	45	496	8.06	Bond with yield
B5	204	51	489	9.58	Bond with yield
B6	252	53	520	8.24	Bond with yield
B7	200	26	238	4.76	Bond
B8	250	27	247	3.95	Bond

* The embedded length was measured for the failed side.
(All beams with the same bar diameter.)

Table (9): Beams tensile strength results.

Beam designation	f'_{ct} * (MPa)	f'_{ct} / f'_c	ACI-code equation	Measured/calculated Tensile strength
B1	3.12	9.7	3.16	0.98
B2	3.02	10.1	3.06	0.99
B3	3.70	8.6	3.67	1.01
B4	3.71	8.24	3.76	0.99
B5	4.76	9.33	4.00	1.18
B6	4.83	9.11	4.08	1.18
B7	2.48	9.5	2.86	0.86
B8	2.41	8.9	2.91	0.83

- Concrete tensile strength by indirect test.
- The ACI 05-code equation $f'_{ct} = 0.56\sqrt{f'_c}$ (R11.2.1.1)

Table (10): results of loaded end and free end slip.

Beam designation	Loaded end slip (mm)	(SCC/NC) % of loaded end slip*	Free end slip (mm)	(SCC/NC) % of free end slip*
B1	0.58	28	0.46	13
B2	0.73	18	0.35	34
B3	0.61	36	0.28	85
B4	0.75	21	0.22	113
B5	1.16	157	0.20	160
B6	1.34	116	0.15	213
B7	0.45	100	0.52	100
B8	0.62	100	0.47	100

* Ratio of (SCC/NC) loaded end slip for the same embedded length i.e. (B1, 3, 5/B7 and B2, 4, 6/B8)

Figure (3): Crack patterns for beam specimen B2 with compressive strength 30MPa

Figure (4): Crack patterns for beam specimen B6 with compressive strength 53MPa

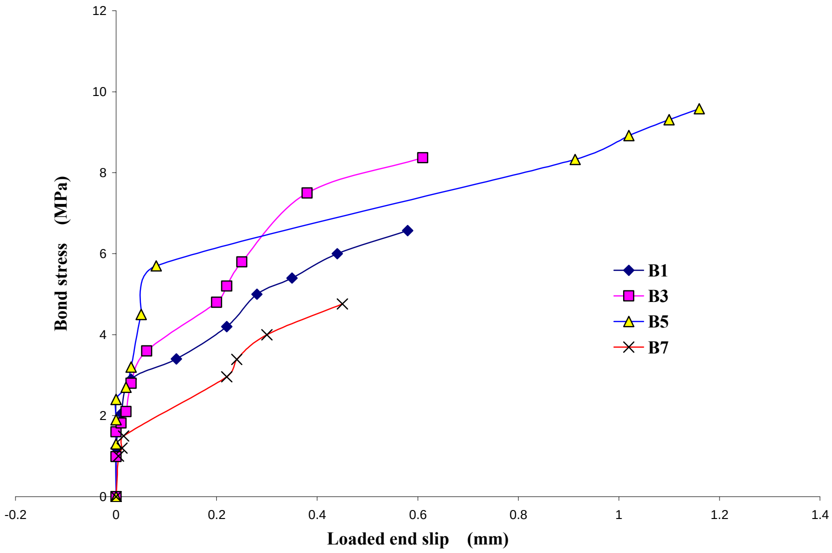

Figure (5): Bond stress-loaded end slip for beams had same embedded length (l_d = 200mm) and different compressive strength

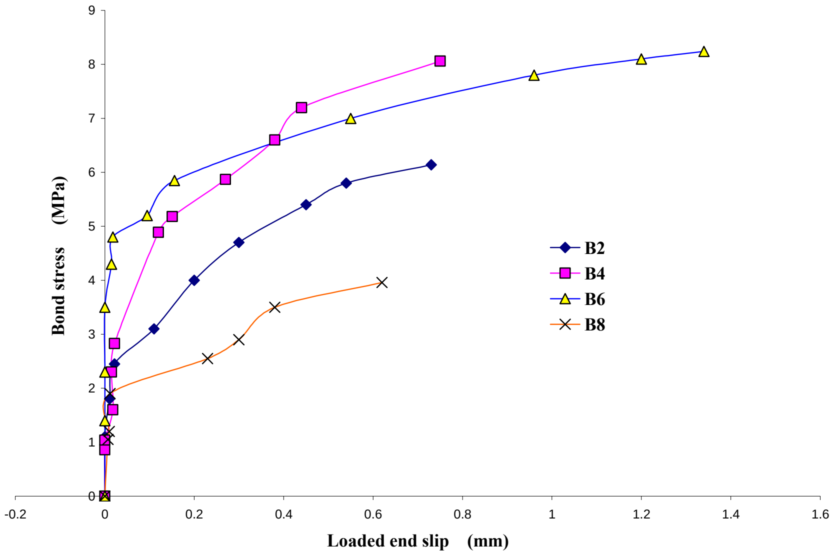

Figure (6): Bond stress-loaded end slip for beams had same embedded length (l_d = 250mm) and different compressive strength

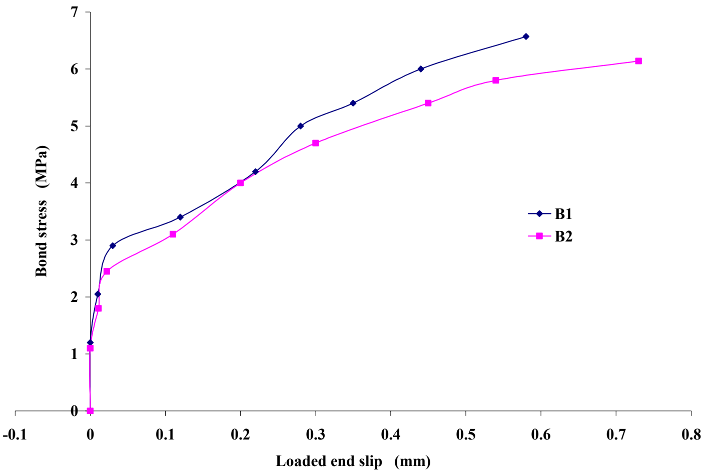

Figure (7): Bond stress-loaded end slip for beams had same compressive strength ($f'_c \cong 30$MPa) and different embedded length

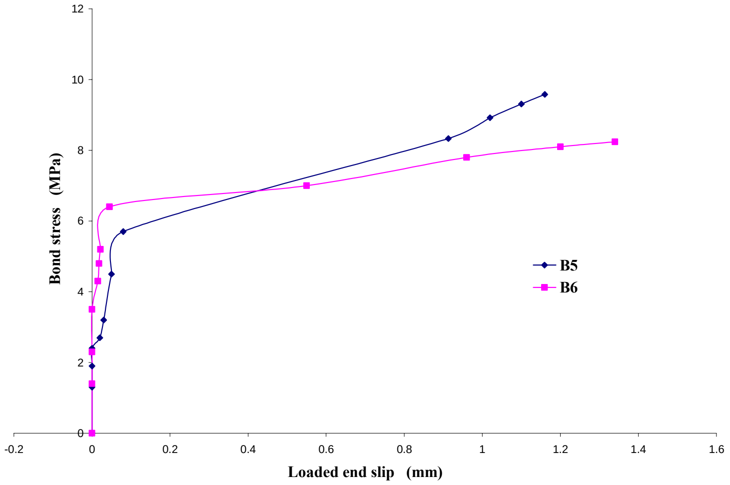

Figure (8): Bond stress-loaded end slip for beams had same compressive strength ($f'_c \cong$ 52MPa)and different embedded length

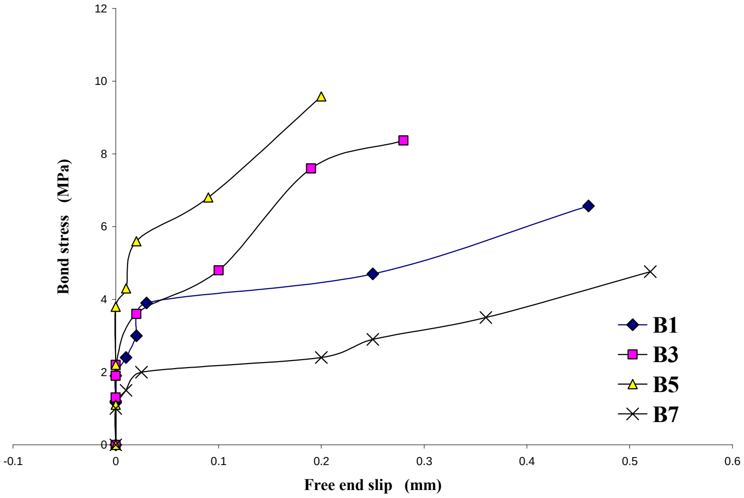

Figure (9): Bond stress-free end slip for beams had same embedded length ($l_d = 200$mm) and different compressive strength

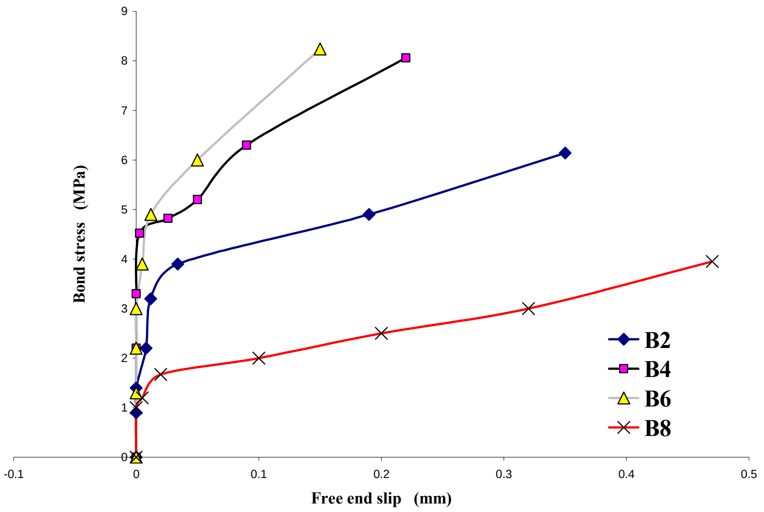

Figure (10): Bond stress-free end slip for beams had same embedded length ($l_d = 250$mm) and different compressive strength

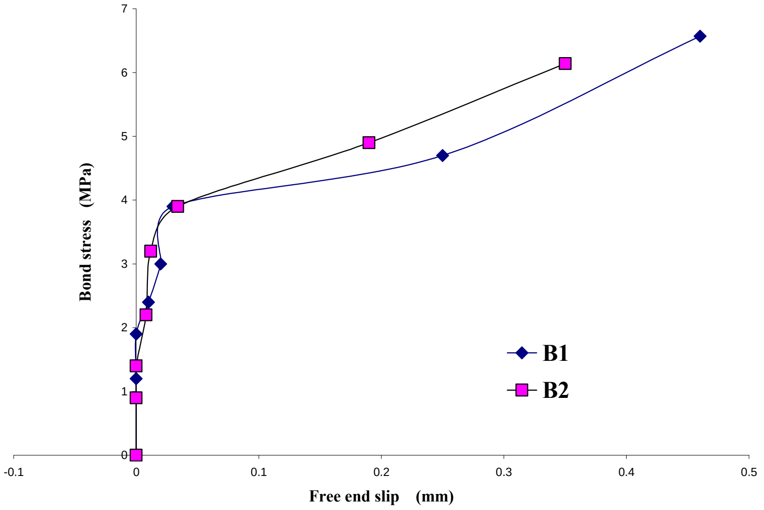

Figure (11): Bond stress-free end slip for beams had same compressive strength ($f_c' \cong 30$MPa) and different embedded length

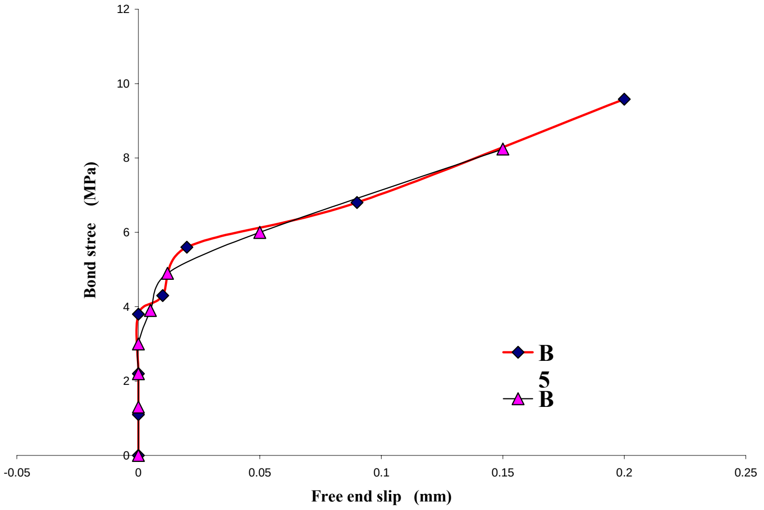

Figure (12): Bond stress-free end slip for had same compressive strength ($f_c' \cong$ 52MPa)and different embedded length

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NOTATIONS:

A : Bar cross-section area (mm^2)
d_b : Bar diameter (mm)
l_d : Effective embeddedlength (mm)
f_s : Steel stress (MPa)
SCC: Self compacted concrete
u : Bond stress (MPa)