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# Investigation of Bond Strength of Reinforcing Steel Bars In Self-Compacting Concrete

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**ملخص البحث**

الخرسانة الذاتية الدمك هى خرسانه ذات سيولة عالية يمكن أن تتدفق بثبات تحت تأثير وزنها , وتمر بين أسياخ التسليح وتملأ الفرم دون الحاجه الى هز او دمك . تطبيق الخرسانة الذاتية الدمك له تأثير فعال فى حل صعوبات الصب فى الفرم المعقده وكثيفة التسليح , التماسك الكافى فى وصلة التسليح هو واحد من أهم المتطلبات فى تصميم العناصر الخرسانية المسلحة , ولذلك هناك حاجه لدراسة مقاومة التماسك لوصلة صلب التسليح فى منطقة الشد للخرسانة الذاتية الدمك .الهدف الرئيسى من هذا البحث هو دراسة مقاومة التماسك لوصلات التراكب لصلب التسليح فى منطقة الشد و الخرسانة الذاتية الدمك المنتجة محليا" ومقارنتها مع الخرسانة التقليدية (المهزوزة) .

## ABSTRACT

The present experimental research work was conducted to study the effect using Self compacting ( SCC ) on the bond behavior of tension Lap – spliced reinforcing steel. Fifteen R-section full scale simply supported beam with cantilever reinforcing specimens with different configurations under two point load beams Self compacting normal and high strength . All beams have a total depth 300 mm , width 200 mm and length of specimens 2700 mm. The main variables of this study were the compressive strength, Splice Length , confinement at tested zone , concrete cover and concrete type. The general deformational behavior of the tested beams was examined and reported (crack patterns, deflections, strains of concrete and steel). The observed behavior of the SCC specimens up to failure greatly encourages the use of SCC in all structural elements. The effect of the studied variables are presented and discussed.

**KEYWORDS:** Self compacting concrete, Beams, Flexural, lap Splice, Bond Behavior.

## 1. INTRODUCTION

Self-compacting Concrete (SCC) is a highly fluid yet stable concrete that can flow consistently under its own weight, pass between reinforcing bars, and fill in formwork without any need for vibration or compaction. The application of SCC effectively resolves the difficulties of concreting in situations with complicated formwork and congested reinforcements. The adequate bond in splice is one of the essential requirements in the design of reinforced concrete elements. Therefore, there is a need to investigate the bond strength of tension lap-spliced reinforcing steel bars and self-compacting concrete.

The Materials used in SCC are the same as in conventional concrete except that an excess of fine material and chemical admixtures are used. Also, a viscosity-modifying agent (VMA) will be required because slight variations in the amount of water or in the proportions of aggregate and sand will make the SCC unstable, that is, water or slurry may separate from the remaining material. The powdered materials are fly ash, silica fume, lime stone powder, glass filler and quartzite filler. The use of pozzolanic materials helps the SCC to flow better. These materials includes cement , fine aggregates , Dolomite , Lime stone powder , Silica fume , (VEA) viscosity enhancing agents and mixing water.

Due to its very low tensile strength, concrete, by itself, would be a poor structural material to use in members resisting anything but a concentric axial compressive load. The tensile strength of concrete is generally only 10% of its compressive strength. However, the addition of steel reinforcing bars in the areas of the cross section of the member experiencing tensile stresses has proven to be a suitable solution to overcoming the poor tensile strength of concrete. The high tensile strength of steel is able to withstand the tensile stresses upon failure of the concrete. In order to obtain complete composite behavior between the reinforcing steel and the concrete, the tensile stresses must be fully transferred to the steel from the concrete. This transfer of stresses is facilitated by an adequate bond between the steel reinforcing bars and concrete. The three modes of stress transfer from concrete to deformed steel reinforcement are through chemical adhesion, friction along the steel-concrete interface, and bearing resistance of the ribs on the steel against the surrounding concrete, Experimental study**:** It includes construction and testing of fifteen full-scale simply supported beam with cantilever reinforcing specimens with different configurations under two point load. The main objective of the test program is to investigate the effect of the main parameters. Several trials have been made to develop the current test program to meet the previously mentioned objectives.

## 2. EXPERIMENTAL PROGRAM

Specimens used in this research consisted of six group, 15 R-section beams Self compacting normal and high strength. All beams have a total depth 300 mm , width 200 mm and length of specimens 2700 mm . Figure 1 to figure 6 show the geometry and dimensions of the tested specimens.

### 2.1 Concrete Mixtures Evaluated

Many trial mixes were done to have various values of $F_{cu}$ with changing the percentage of W/C (water cement ratio) and amount of Viscosity agent and the final quantities required by weight for one cubic meter of fresh concrete for the specimens as given in Table 1 , Table 2 and Table 3. All reinforcing steel used in the current research was high strength deformed steel. In order to determine the mechanical properties of the reinforcing steel, Three specimens of each diameter were prepared and tested under uniaxial tensile load . The average yield and ultimate tensile strength were 586 and 719 MPa for diameter 10 mm, and 563 and 899 MPa for diameter 12 mm. SCC can be designed to fulfil the requirements of EN 206 regarding density, strength development, final strength and durability ,Due to the high content of powder , SCC may show more plastic shrinkage or creep than ordinary concrete mixes . These aspects should therefore be considered during designing and specifying SCC . Current knowledge of these aspects is limited and this is an area requiring further research . Special care should also be taken to begin curing the concrete as early as possible . The workability of SCC is higher than the highest class of consistence described within EN 206 and can be charcterised by the following properties:

- Filling ability
- Passing ability
- Segregation resistance

A concrete mix can only be classified as self-compacting concrete if the requirements for all three characterised are fulfilled. The three mixes proportions/m3 by weight are shown in table (1).

**Table** Mixture Proportions in Kilograms per Cubic Meters (Kg/m$^3$)for SCC1,SCC2 and NCC.

| Materials | SCC1 $F_{CU}$=35MPa | SCC2 $F_{CU}$=65MPa | NCC $F_{CU}$=35MPa |
|---|---|---|---|
| Cement | 380 | 427.5 | 350 |
| Dolomite (4-15mm) | 616 | 508 | 547 |
| Dolomite (15-19mm) | 264 | 285 | 650 |
| Sand (0-4) | 935 | 932 | 753 |
| Mixing Water | 192.5 | 153 | 136.5 |
| Silica Fume | ---- | 22.5 | ---- |
| Lime Stone Powder | 112.5 | ---- | ---- |
| High-range water reducing admixture /water reducer* | 6 | 8 | 5.5 |

*For SCC, high performance superplasticiser concrete admixture (Viscocrete-3425) used , melamine sulfonate polymer based ordinary water reducer(Sika Control 40 ) is used in NCC mixture .

### 2.2.1. Test Specimens

Specimens used in this research consisted of six group , 15 R-section beams Self compacting normal and high strength . All beams have a total depth 300 mm , width 200 mm and length of specimens 2700 mm .

### 2.2.2. Test Setup

Different types of instrumentations were used to monitor the specimen behavior. The following measurements were recorded during the specimen testing. The actuator load was measured using (400KN) capacity load cell attached to the movable end of the actuator. Deflections along the beam span and cantilever free end were monitored using four Dial gages as shown in figure 1. The concrete strains at the max bending ( negative and positive ) were measured using extensometer and demic points the distance between them (100 mm) and they have been fixed on the concrete surface at maximum bending moment and at mid span as shown in figure 1..The reinforcing steel strain were measured at the start , the middle and the end of splice length using 120-ohm electronic strain gages .

### 2.2.3. Test Procedure

The test specimens were tested under monotonic load. The load was applied with a uniformly increasing displacement until failure. All specimens were simply supported in four points bending test as beam with cantilever as shown in figure 2 Each specimen was supported over two rigid supports with 1800mm simple span with 600mm cantilever span and load was applied using 300 KN capacity hydraulic actuator with max stroke 100 mm .The load was divide to two concentrated loads 1500mm apart ( at cantilever free end and beam mid-span) using rigid steel spreader beam as shown in figure 2 .

The actuator was driven in displacement control and the load was applied against a reaction steel frame as shown in figure 2. Data form load cell, dial gages, straining gages and extensometer were recorded manually during the test.

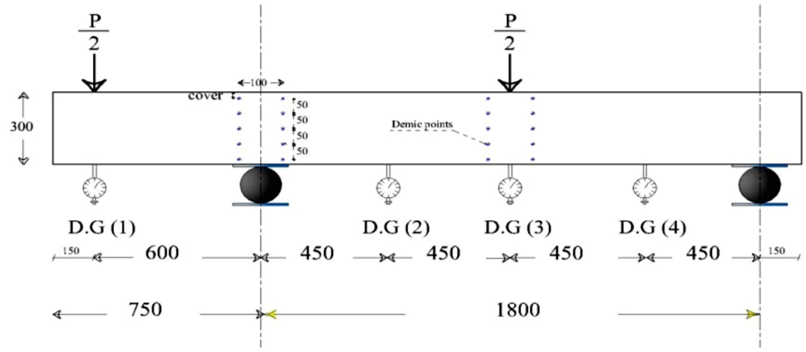


**Fig.1**The positioning of Dial gages and Demic point son specimens

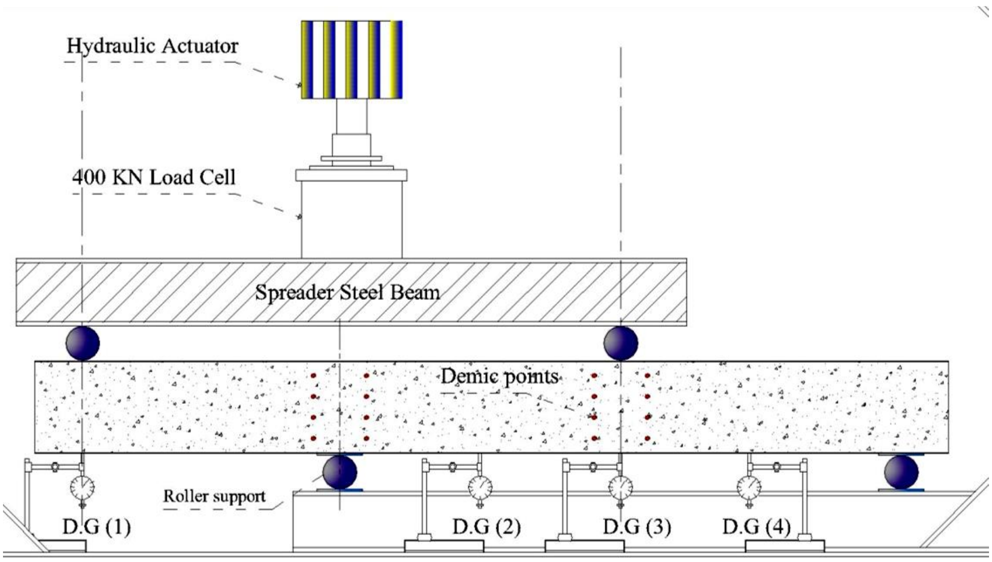


**Fig.2** Test setup

### 2.2 Time-Dependent Flexural Behavior of Reinforced LWC Beams

This experimental program used for investigation of the flexural behavior of reinforced LWC beams under sustained load with time, which is important because creep increases the deflection with time and may be a critical consideration in design.

### 2.3.1. Test Specimens

Specimens used in this research consisted of six group , 15 R-section beams Self compacting normal and high strength . All beams have a total depth 300 mm , width 200 mm and length of specimens 2700 mm . figure 3 to figure 7 show the geometry and dimensions of the tested specimens .

**Table 2** Details of beam specimens

| Groups | Beam | Conc. type | Conc. Strength (MPa) | TOP R.F.T.S | Bottom R.F.T.S | Stirrups details within tested zone | | | Conc.Cover (mm) | LAP Length |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Diameter (mm) | Spacing (mm) | Fy (MPa) | | |
| Group 1 | B1 | SCC | 35 | 2 Ø 12 | 3 Ø 12 | Ø 10 | 100 | 586 | 20 | 50%Ld |
| | B2 | | | | | | | | 30 | |
| | B3 | | | | | | | | 50 | |
| Group 2 | B4 | SCC | 35 | 2 Ø 12 | 3 Ø 12 | Ø 10 | 100 | 586 | 30 | 75%Ld |
| | B5 | | | | | | 150 | | | |
| | B6 | | | | | | 200 | | | |
| Group 3 | B7 | SCC | 35 | 2 Ø 10 | 3 Ø 12 | Ø 10 | 50 | 586 | 30 | 25%Ld |
| | B8 | | | | | | | | | 50%Ld |
| | B9 | | | | | | | | | 100%Ld |
| | B10 | | | | | | | | | No splice |
| Grou | B11 | SCC | 35 | 2 Ø 10 | 3 Ø 12 | Ø10 | 50 | 586 | 50 | 25%Ld |
| Group 5 | B12 | SCC | 65 | 2 Ø 10 | 3 Ø 12 | Ø10 | 50 | 586 | 30 | 25%Ld |
| | B13 | | | | | | | | | 50%Ld |
| Group 6 | B14 | NCC | 35 | 2 Ø 10 | 3 Ø 12 | Ø10 | 50 | 586 | 30 | 25%Ld |
| | B15 | | | | | | | | | 50%Ld |

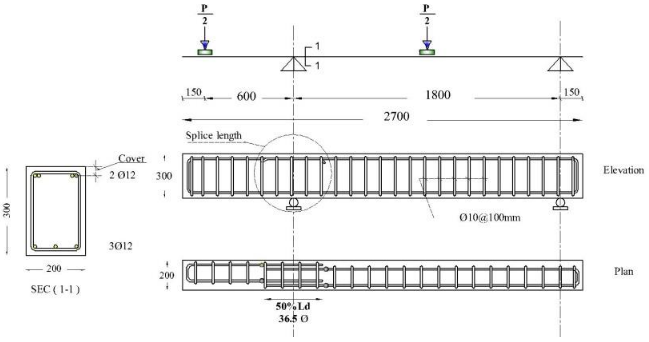


**Fig.3** Geometry and dimensions of Group 1 ( B1,B2,B3)

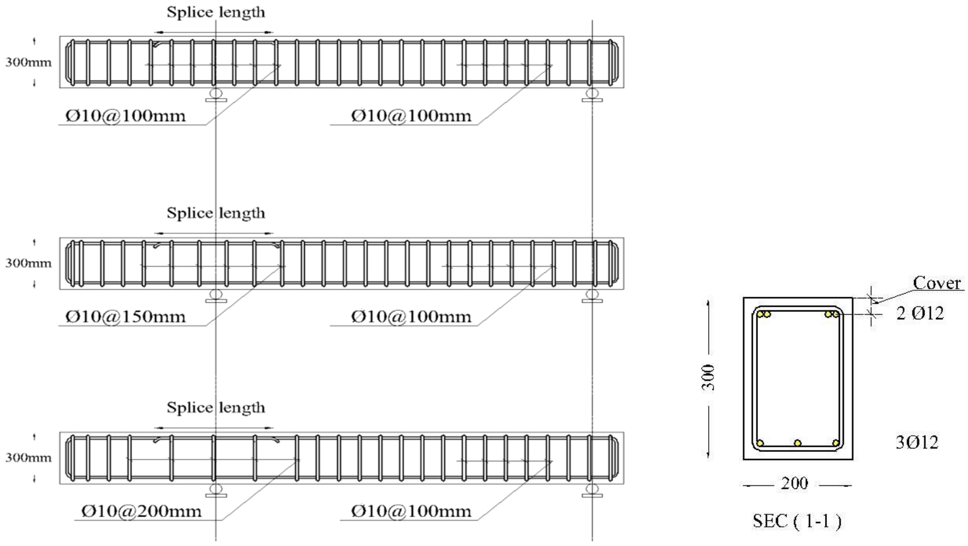


**Fig.4** Geometry and dimensions of Group 2

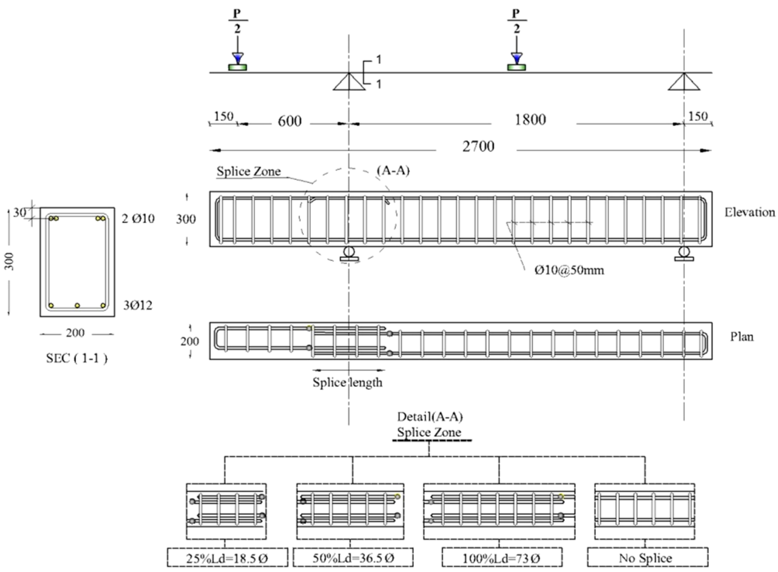


**Fig.5** Geometry and dimensions of Group 3

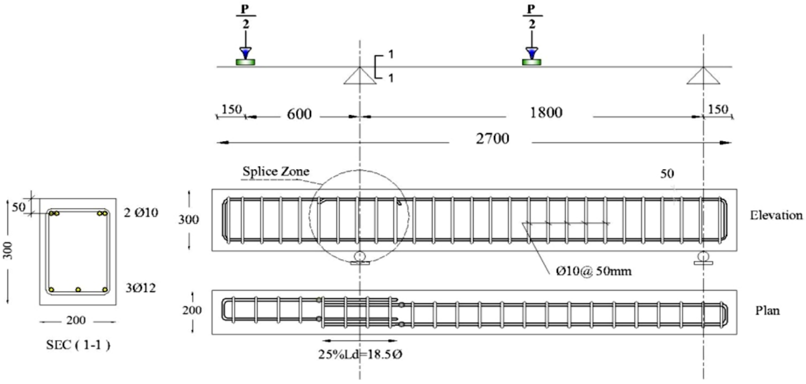


**Fig.6** Geometry and dimensions of Group 4

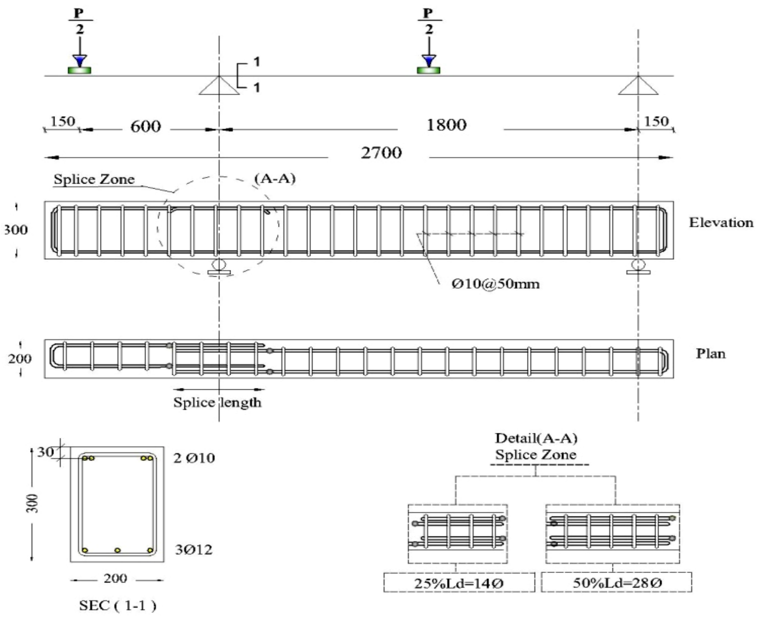


**Fig.6** Geometry and dimensions of Group 5

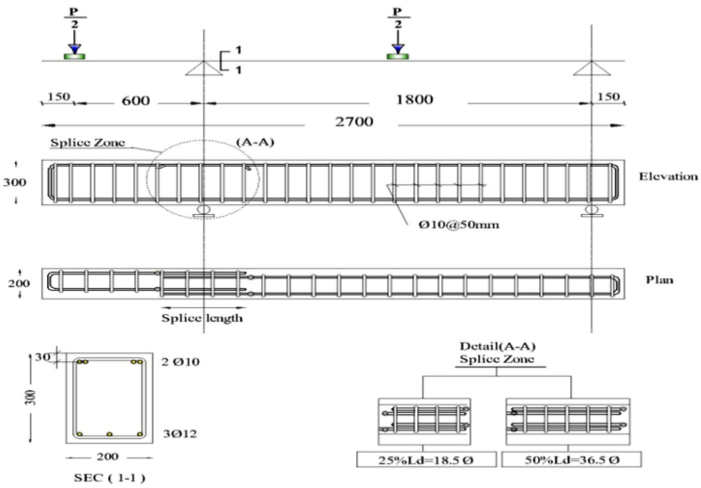


**Fig.7** Geometry and dimensions of Group 6

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

### 3.1 Mechanical Properties of Concrete

This section presents the properties of the materials used in the experimental program . These materials includes cement , fine aggregates , Dolomite , Lime stone powder , Silica fume , (VEA) viscosity enhancing agents and mixing water.and mean values of mechanical properties are given in table (3).

**Table 3** Mechanical properties of the three concrete mixtures

| Time | Compressive Strength (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SCC 1 | | | SCC 2 | | | NCC | | |
| **After 3 days** | 18 | 20 | 22 | 37 | 35 | 33 | 20 | 22 | 25 |
| **After 7 days** | 33 | 31 | 28 | 57 | 56 | 54 | 29 | 29 | 33 |
| **After 28 day** | 37 | 33 | 35 | 68 | 62 | 65 | 35 | 35 | 38 |

### 3.2 Adequacy of Lap Splice Length According to The ECP203-2007 (Behavior of Group 3 (B7, B8, B9, B10))

In this section the behavior of beams B10 (the reference beam with no splice ) and (B7, B8, B9) with splice (18.5Φ, 36.5Φ, 73Φ) respectively, is compared in order to examine the adequacy of lap length according to the ECP203-2007 code.

#### 3.2.1 Load Deflection Relationship

The load-deflection curves of beams B7, B8, B9 and B10 are shown in figure 8.

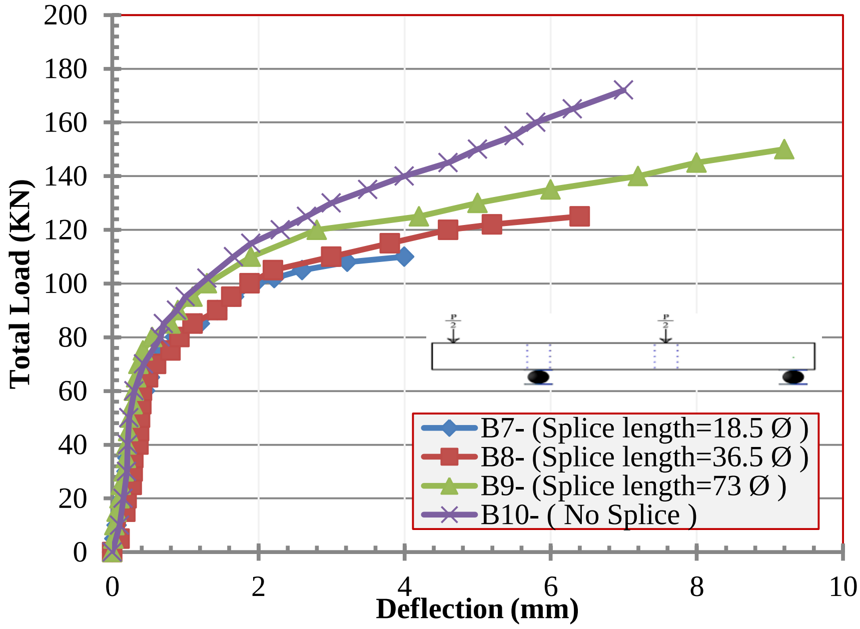


**Fig 9** Beams (B7,B8 ,B9 ,B10): Load-Deflection curve at D.G1

From the Figure 9 the first crack appeared at load equal to 40KN for beams B9 and B10 , 35KN for B8 and 20KN for B7 . Thus, the influence of lap length in beams on cracking load is very obvious.From the curve the yield point is much more defined for B9 and B10 than for B7 and B8.

Upon the area under the curve (P-Δ Curve) of B8 and B7 is about 60.4% and 44.9% of that of B9, The smaller ductility of beam B7 in comparison to beam B9 can be attributed to the lap length (100%Ld) according to the ECP203-2007 of B9 which enable this beam to exhibit larger deformation befor failure.It can be stated that lap length of B9 according the ECP succes to give more ductility than the reference beam B10 (with no splice) because of the area under the curve of B10 is about 90.4% of that of B9 which means that B9 has larger ductility.

### 3.2.2 Stress Along Lap Splice and Bond Stress at Splice

Splice length is one of the most important parameters affecting the strength of the splice. Thus, the effect of splice length was clear on steel stress value along splice length. The relation between the steel stress and the splice length of Group (3 and 5) are shown in Figure 9

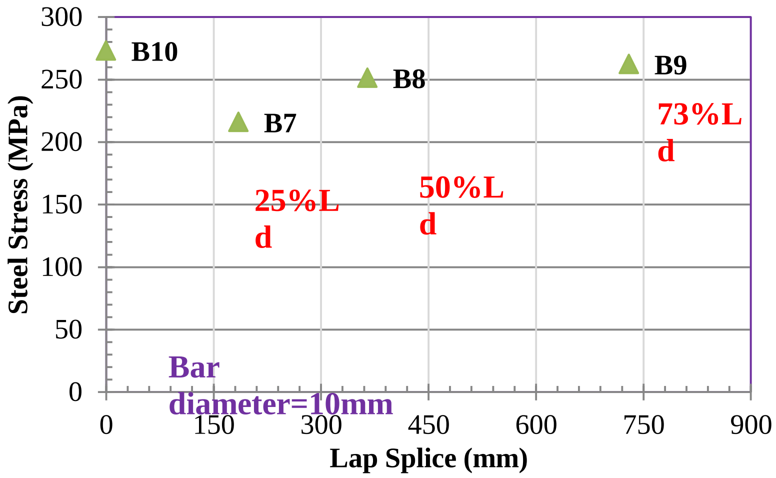


**Fig 10** The Relation Between The Steel Stress and The Splice Length of Groups 3

Figure10 shows the relation between the steel stress and the splice length. It is clear from the Figure, the steel stress was affected by splice length, where the maximum steel stress was (273.2MPa) of reference beam B10 (with no splice). The steel stress of B7 and B8 is about 69.5% and 74.3% of B10.The smaller steel stress of beams B7 and B9 in comparison to B10 can be attributed to the continuous steel bar of B10 which enable this beam to exhibit larger steel stress before failure and smaller lap length affected on bar stress. For beam B9, the steel stress is about 96% of B10. It is can be noted that splice length according to ECP203-2007 (100%Ld=73Φ) of beam B9 which enable this beam exhibit larger steel stress than B7 and B8.

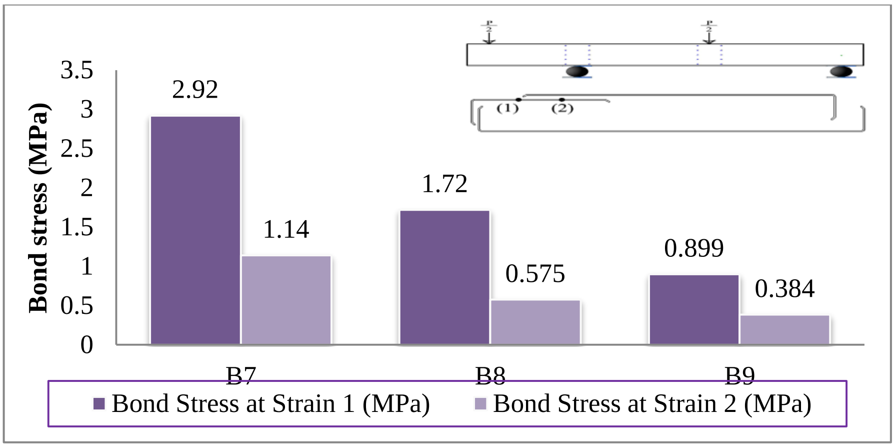


**Fig 11** Bond Stress Along Lap Splice at Strain 1 and 2 for Group 3

The tendency of the ultimate bond stress to be higher for shorter splice length is clearly shown in Figure(4.). From Figure show the bond stress value of beams B7 and B12 had almost the same of bond stress .Which means the affect of the compressive strength to increasing the bond stress, Although both beams had splice length equal to (25%Ld). The ultimate bond stress of beam B8 was about 84% of beam B13. The smaller ultimate bond stress of B8 compared with that of beam B13 is a result of using concrete with smaller strength.

### 3.3 Influence of Confinement at Splice (Behavior of Group 2 (B4, B5, B6))

In this section the behavior of beams B4 (with stirrups Φ10@100mm ) , B5 (with stirrups Φ10@150mm)and B6 (with stirrups Φ10@200mm), is compared in order to examine the influence of confinement at splice in lap splice (75%Ld= 55Φ).

#### 3.3.1 Load Deflection Relationship

The load-deflection curves of beams B4, B5 and B6 are shown in Figure11

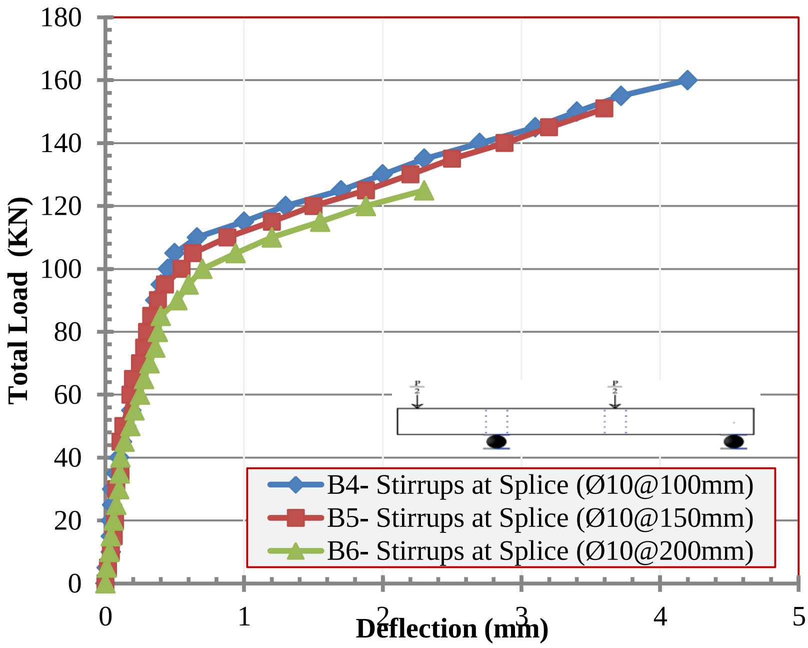


**Fig 12** Beams (B4,B5,B6): Load – Deflection curve at D.G1

From the Figure11 Where it can be noticed that both beams B4 and B5 had the same crack load. This can be attributed to the similarity of both beams and the difference in stirrups intensity (increasing spacing between stirrups from 100 to 150 mm) dose not affect the initiation of first crack but governes the propagation of cracks up to failure as mentioned befor.
From the area under the load-deflection curves of both beams B4 and B5 , It was found that this area of B5 is about 78% of B4 and the area of B6 is about 37% of B4 which means that beam B4 has larger ductility. This can be correlated to the influence of higher stirrups intensity within the reagion of un constant moment.It also noted that the contribution of stirrups in improving ductility in beams (normal strength self-compacting concrete) is significant because of the large lateral deformation of NSSCC. These results concede with that obtained by Ferguson and Breen[] where they stated that stirrups eliminate the sudden and violent failure.

### 3.3.2 Stress Along Lap Splice and Bond Stress at Splice

The effect of confinement at splice zone was clear on steel stress value along splice length. The relation between the steel stress and the splice length of Group 2 are shown in Figure(4.46).

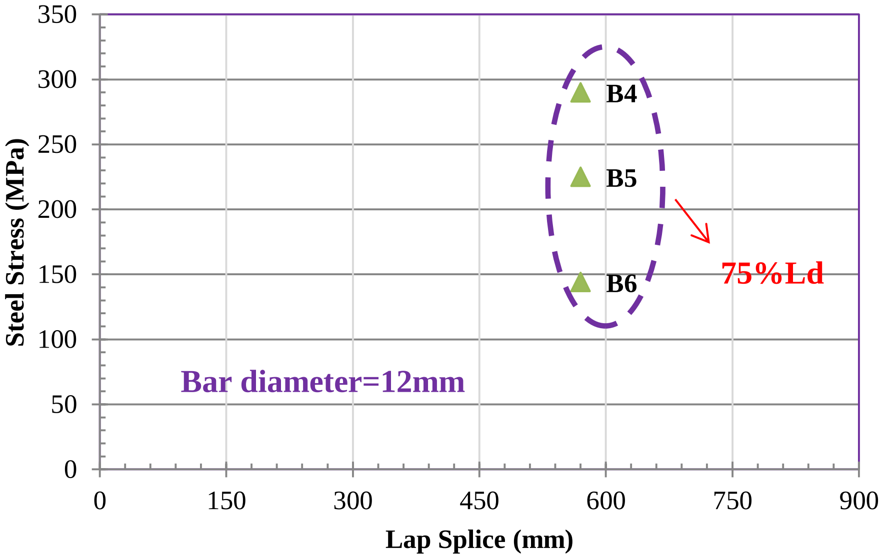


**Fig 13** The Relation Between The Steel Stress and The Splice Length of Group 2

Figure(4.) shows the relation between the steel stress and the splice length. It is clear from the Figure, the steel stress was affected by confinement at splice zone, where the maximum steel stress was (290MPa) of B4 (with stirrups Φ10@100mm at splice). The steel stress of B5 and B6 is about 77.6% and 49.7% of B4.The smaller steel stress of beams B6 in comparison to B4 can be attributed to the high level of confinement at splice zone of B4 than others, which enable this beam to exhibit larger steel stress before failure .
The concrete strength variation can be eliminated by dividing the steel strength by square root of the concrete compressive strength (Normalized steel stress).Figure13 shows the relation between the normalized steel stress and the splice length.

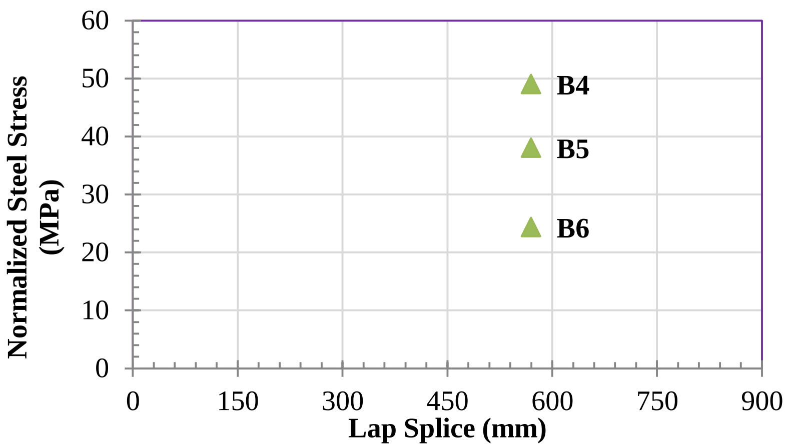


**Fig 14** The Relation Between The Normalized Steel Stress and The Splice Length of Groups 2

**Figure(14** shows the relation between the normalized steel stress and the splice length of Group 2. Increasing the spacing between stirrups at splice length from (100 to 200mm) leads to an decrease in the normalized steel stress about 50% .

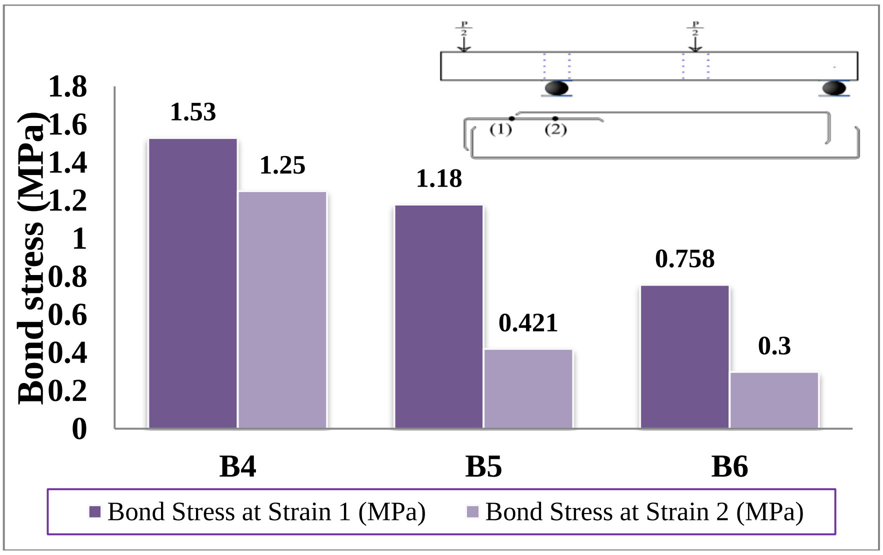


**Fig 15 Bond Stress Along Lap Splice at Strain 1 and 2 for Group 2 (B4,B5,B6)**

From Figure(4.) show that beam B4 had the maximum bond stress value ,Which the bond stress of beams B5 and B6 is about 77% and 49.5% of B4 .Which means the affect of low confinement at splice to decreasing the bond stress, Although the three beams had splice length equal to (75%Ld).

## 4. CONCLUSIONS

The main conclusions that can be drawn from the performed experimental and analytical studies are as follows:

1- The steel doesn't reach the yield stress at splice zone even the splice length equal to (25% , 50% , 75% of that given by the ECP203-2007 code) is used, the failure is due to bond and splitting failure.

2- Using the lap splice according to the ECP203-2007 the ultimate load doesn't increase but the ductility improves.

3- When the lap length increase, the splitting stress and the bond stress decrease.

4- In order to prevent the early cracks at splice ends additional transverse reinforcement is necessary.

5- Using lap splice (25%Ld) or (18.5Φ) accelerates cracks and cause splitting brittle failure.

6- Increasing the concrete cover decrease the moment capacity and the energy absorption.

7- Increasing the concrete compressive strength increase the moment capacity and the bond stress when a splice length 50% of splice length according to the ECP203-2007 .

8- Beams with high concrete compressive strength give a cracking load higher than beams with lower concrete compressive strength for the same splice length.

9- SCC beams give an ultimate load and more ductility higher than NCC beams for the same concrete compressive strength and splice length.

10- SCC beams give an ultimate load and more ductility higher than NCC beams for the same concrete compressive strength and splice length.

11- Increasing stirrups intensity at splice zone improves the ductility and make the failure more ductile.

12- Increasing stirrups intensity don't have a significant effect on the strength of beams.

13- To eliminate the cracks at lap ends stirrups must be concentrated (with spacing 50-100mm) before and after the splice.

14- In order to prevent the shear failure at support and the crack at lap ends increase the stirrups intensity at lap zone.

15- Lap splice (50% of lap splice according to the ECP203-2007) in SCC beams give a moment capacity and great behavior at failure more than NCC beams.

16- Using lap splice according to ECP203-2007 dose have almost the moment capacity but improve the ductility.

17- As the cover section increases, the bond stress decreases up to a certain limit

18- The current formulae of lap length which (75% lower than lap length according to ECP203-2007) requires adjustment.

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