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Bond Strength of Reinforcing Steel Bars In Self-Compacting Concrete Beams at Shear zone

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ABSTRACT

Self-compacting concrete (SCC) represents an innovation in the building industry due to its workability. This type of concrete can flow under its own weight, fill in formwork and pass between bars without need compaction, but the mixture proportions for SCC differ essentially. The higher powder content, limited volume and nominal maximum size of aggregate, larger quantity of super-plasticizers make design requirements in achieving the self-compacting concrete. The bond between SCC and reinforcing steel bars is an essential requirement for design of reinforced concrete structures. The current study investigate the effect of various parameters that affect the bond behavior between SCC and steel rebars at the maximum shear strength zone such as : concrete compressive strength, splice length ,concrete cover , the effect of confining steel and level of confinement, Evaluate the applicability of various lap splice equations, in different building codes and standards, for calculating lap splice in self-compacting concrete beams ,Finally compare between bond behavior of lap splice in conventional concrete and SCC.

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Keywords: Self-compacting concrete, Bond strength, compaction, Full scale beam, Lap spliced bars.

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INTRODUCTION

Adequate bond between concrete and reinforcing bars in a splice is an essential requirement in the design of reinforced concrete structures. In the last 25 years, The Interest in SCC grows rapidly and now it is widely used in bridges and high rise building construction. A typical application example of Self-compacting concrete is the two anchorages of Akashi-Kaikyo Bridge opened in April 1998 and the suspension bridge with the longest span in the world (1991 m). The bond between steel and concrete has an important influence on the behavior of reinforced elements in the cracked stage [19]. Deflections are influenced by the distribution of bond stresses along the reinforcement bars and by the slip between the bar and the surrounding concrete. Bond has been the subject of different studies on SCC, but the conclusions are very contradictory: some indicate that bond strengths of reinforcing bars in SCC are higher than those measured for NVC, other researchers see no differences between or even lower strengths. Most studies agree that the bond strength of rebars in SCC is larger than that in NVC. Many researches were reported on bond strength between concrete and deformed bars for both normal strength and high strength concrete. Experimental tests were done and analytical equations were proposed by some researchers.

Various investigations have been carried out in order to make self-compacting concrete a standard one [9]. The items to be solved are summarized as, self-compactability testing method, mix-design method including, acceptance testing method at job site, and new type of powder or admixture suitable for self-compacting concrete. The European Guidelines for Self-Compacting Concrete [3] represents a state of the art document addressed to those specifiers, designers, purchasers, producers and users who wish to enhance their expertise and use of SCC. The guidelines have been prepared using the wide range of experience and knowledge available to the European Project Group.

During the last ten years, few researches were conducted on bond strength of self-compacting concrete [1–7]. In 1990, Ato- rod Azizinamini et al. [1] tested a total of 18 beam specimens with two or three bars spliced. The main variables were (a) Concrete compressive strength f^{0}_{c}, (b) Splice length; and (c) Casting position. The results showed that normalized bond strength decreases as concrete compressive strength increases with a rate of decrease increases as the splice length increases. In the case of normal strength concrete, the top bar demonstrated approximately 8% reduction in bond capacity com- pared to bottom cast bars. As indicated by comparison with the results, top bars, as defined by the ACI 318-11 [10], pro- duce higher bond capacity when HSC is utilized.

Yerlici and Ozturan [2] conducted a research program for testing 53 eccentric pullout test specimens. Tested specimens were divided into four groups, where only a single parameter varied in each group. For the first three groups, the variable parameters were the concrete compressive strength, the rein- forcing bar diameter, and the thickness of clear concrete cover. These parameters varied as 60, 70, 80, and 90 MPa (8700,10,150, 11,600, and 13,050 psi), 12, 16, 20, and 26 mm (No.4, 5, 6, and 8), and 15, 20, 25, and 30 mm (5/8, 3/8, 1, and1-1/8 in.), respectively. The variable parameter of the fourth test group was the amount of web reinforcement that was made up of three closed stirrups spaced at 30 mm (1-3/16 in.), center-to-center, transversely crossing the anchorage length of the longitudinal bars. The amount of web reinforce- ment varied from none to having stirrups made of 3, 4, and 6 mm (D-1, D-2, and D-4) diameter steel wires. It was indi- cated that the average anchorage bond strength varies with the compressive strength of concrete, as$(fc')^{2/3}$.The ACI Code slightly underestimates the effect of concrete strength on anchorage bond resistance when extended to HSC, while it overestimates the effect of concrete cover on anchorage bond resistance when extended to HSC. The research project of Chan et al. [4] included the testing of a full-scale RC wall as the pullout specimen in which pullout reinforcing bars and transverse reinforcement were installed, some walls were SCC while others were cast from ordinary compacted concrete. The main variables were; (a) Concrete compressive strength f^{0}, (b) Height of pull out bar (effect of top bar), and (c) Age of Concrete from 17 h to 28 days. It was concluded that compared to normal concrete NC, SCC exhibits higher bond to reinforcing bars and lower reduction in bond strength due to the top-bar effect. The slow development of compressive strength and bond strength in SCC at early age is generally due to the retarding effect of the carbox- ylic high-range water-reducing admixture used. Almeida et al. [5] tested 66 special set up beam specimens made from 3 SCC mixes. The main variables were (a) Maxi- mum aggregate size, and (b) SCC fluidity. It was found that the bond resistance was not affected by the SCC lack of fluid- ity. It was also found that high performance concretes have a fragile rupture of the bond connection. Also, unless some con- finement reinforcement is provided, the splitting of the con- crete surrounding the bar will occur as the concrete tension strength is reached. Finally, the desirable failure mode, with yielding or slip of the bar, will not occur. The behavior of the beams was similar in the 3 series of tests, even considering the low fluidity of one of the 3 mixes.

Twelve full-scale beam specimens (2000 · 300 · 200 mm) were tested in positive bending [6] with the loading system de- signed to determine the effect of self-compacting concrete (SCC) and the diameter of reinforcement on bond–slip charac- teristics of tension lap-slices. The specimens of lap-splice series were tested with lap-spliced bars centered on the midspan in a region of constant positive bending. The results showed that load transfer within the tension lap-spliced bars embedded in SCC in a reinforced concrete beam was better than that of the tension lap-spliced bars embedded in NC. The beam spec- imens produced from SCC had generally longer cracks in length than the beams produced from NC regardless of the reinforcing bar diameter. The project of Cattaneo and Rosati [7] included the testing of 27 pullout specimens containing one embedded reinforce- ment bar. The main variables were reinforcement bar diame- ter, fiber existence and confinement. Two types of tests were considered: unconfined and confined pullout. The tests showed a significant size effect on bond strength: the smaller bar diam- eter exhibited a higher strength than the larger one. The bond strength of self-consolidating concrete was found to be higher than normal strength concrete. The concrete cover, 4.5B, where B is the bar diameter, was not sufficient to prevent split- ting failure in SCC.

Experimental work

It includes construction and testing of six full-scale simply supported beams with cantilever reinforcing specimens with different configurations under two point loads. The main objective of the test program is to investigate the effect of the main parameters.

Test specimens

The proposed test program has been designed to fulfill the following criteria:
1-Have Suppress the bending failure mode this is because the program discuss the behavior of bond in shear failure at support where there is maximum shear.
2- Getting the bond failure of Lap splice before yield of bars.
3- Evaluate the applicability of various lap splice equations, in different building codes and standards, for calculating lap splice in self-compacting concrete beams.
Table 1 gives a complete description of the test specimens that includes the variables.

Table 1: Test Specimens

Groups	Beams	Conc. Strength (MPa)	TOP R.F.T.S	Bottom R.F.T.S	Stirrups Details Within Tested Zone			Concrete Cover (mm)	Lap Length
					Diameter (mm)	Spacing (mm)	f_y (MPa)		
Group 1	B1	35	2 Ø 12	3 Ø 12	Ø 10	100	586	20	50% Ld
	B2							30	
	B3							50	
Group 2	B4					100		30	75% Ld
	B5					150			
	B6					200			

Materials

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. 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 2 Once all requirements are fulfilled, the mix should be tested at full scale at the concrete plant. Table 3 show the Fresh concrete properties of concrete.

Table 2: Mixture Proportions in Kilograms per Cubic Meters (Kg/m^3)

Materials	**SCC Kg\m^3**
Cement	380
Dolomite (4-15mm)	616
Dolomite (15-19mm)	264
Sand (0-4)	935
Mixing Water	192.5
Silica Fume	----
Lime Stone Powder	112.5

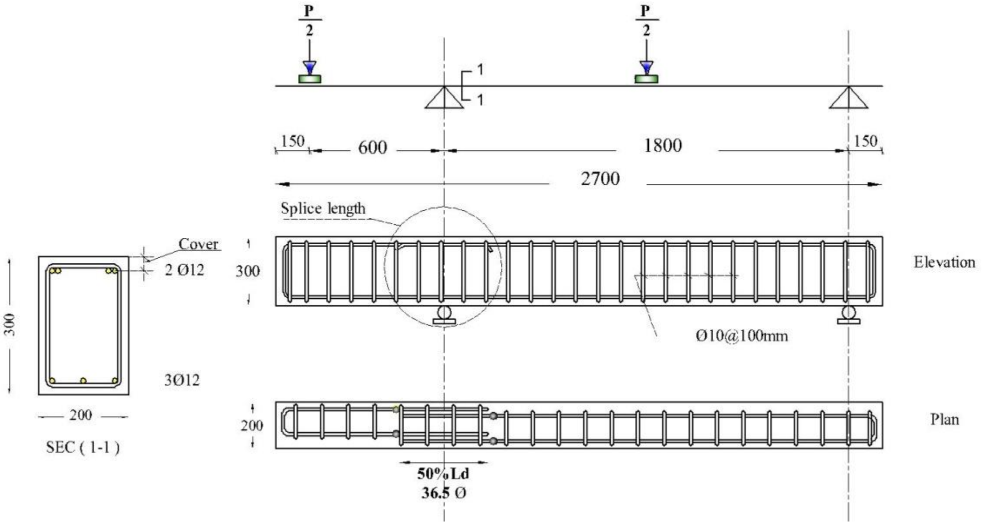
High performance super-plasticizer concrete admixture (Viscocrete-3425) used.

Table 3: Fresh concrete properties of concrete.

Test	**Unit**	**Mix**
		SCC
Slump flow (EFNARC- SF2=660-750)	mm	700
Slump flow (T_{500}) (EFNARC-VS1= 2-5)	Sec	3.2
J - RING (EFNARC=0-10)or(<N.M.S)	mm	3
Slump cone (ECP 203 - 2007=75-125)	mm	----
Is there segregation of aggregates ?		NO

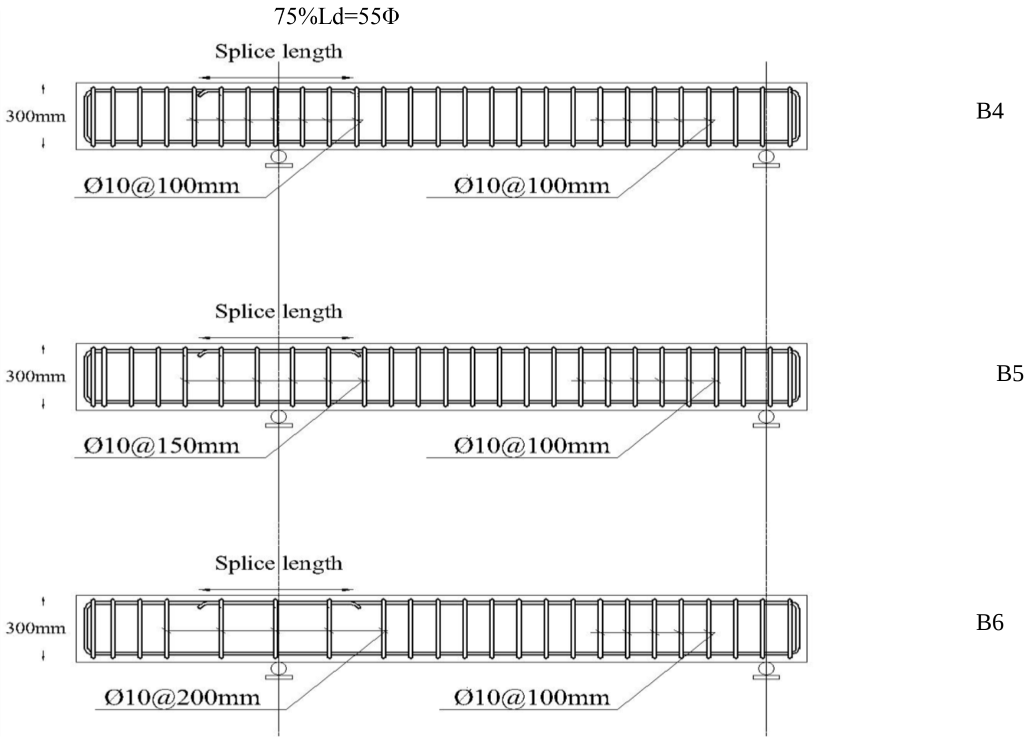
Test procedure

Specimens used in this research consisted of six group, 6 R-section self-compacting beams. All beams have a total depth 300 mm, width 200 mm and length of specimens 2700 mm . Figure 1 to Figure 2 show the geometry and dimensions of the tested specimens.



All dimensions in mm , Cover for beam (B1=20mm, B2=30mm, B3=50mm)

Figure 1: Geometry and dimensions of Group 1 (B1,B2,B3)



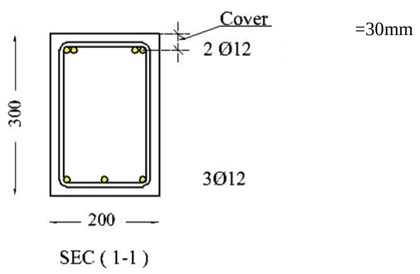


Figure 2: Geometry and Dimensions of Group 2 (B4,B5,B6)

Instrumentations of Specimens

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. The concrete strains at the max shear strength were measured using extensometer and demec points, distance between them (100 mm) and they have been fixed on the concrete surface at maximum bending moment and at mid-span. The reinforcing steel strain was measured at the start, the middle and the end of splice length using 120-ohm electronic strain gages.

Test Setup and Loading 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 test as beam with cantilever as shown in Figure 3. 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 .The actuator was driven in displacement control and the load was applied against a reaction steel frame. Data form load cell, dial gages, straining gages and extensometer were recorded manually during the test.

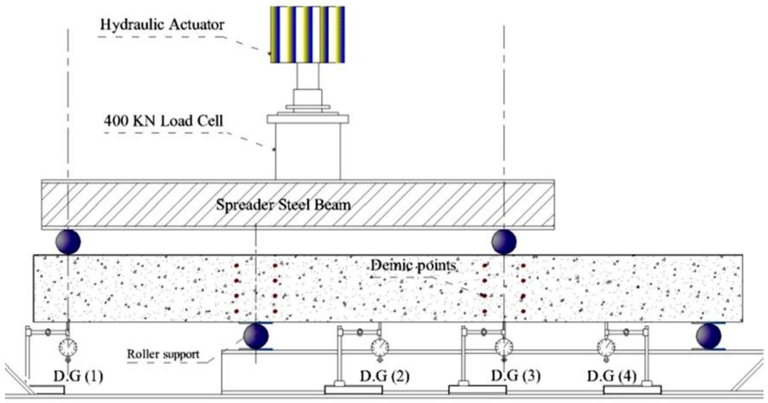


Figure 3 Test setup

Test results

Influence of Confinement at Splice

Load Capacity

The recorded ultimate load of beam B5 and B6 was about 94.4% and 78% of B4,It can be attributed to the low confinement of beam B6 which enable this beam to be more brittle at failure. The spacing between stirrups at lap zone (Φ10@200mm) at the region of maximum shear where the ends of lap splice act as crack initiators and cause the first crack at load 30KN and enable this beam lower moment capacity. From the area under the load-deflection curves of both beams B4 and B5 in Figure12 , 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 maximum shear strength(un constant shear strength.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. Also, these results match with Ralejs results who stated that stirrups prevent the sudden disruption of equilibrium at splice zones.

Ductility Index and Energy absorption

Figure 4 and Figure 5 shows that the ductility and energy absorption decrease with increasing the spacing between stirrups at the lap splice, Which beam B4 have the maximum ductility index equal to 0.6 and E.A equal to 530.61 KN.mm^2 .Using confinement at splice zone (ø10@200mm) decreasing the ductility to 45% and the E.A decrease to 62% according to beam B4.

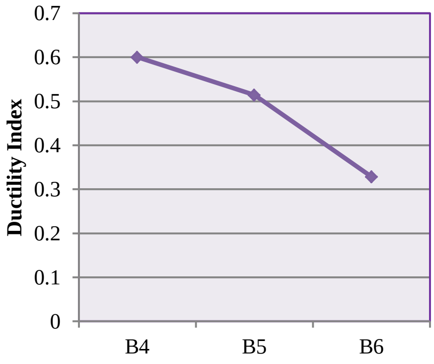


Figure 4: Ductility Index for Group 2

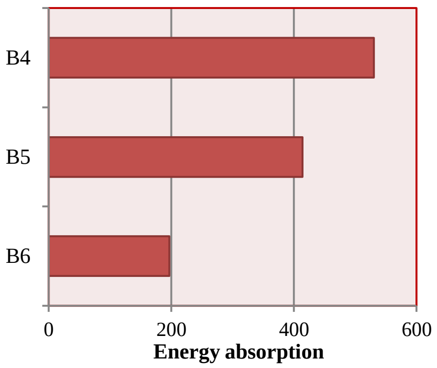


Figure 5: Energy absorption for Group 2

Stress along Lap Splice and Bond Stress at Splice

The steel stress was affected by confinement at splice zone, where the maximum steel stress was (545MPa) of B4 (with stirrups Φ10@100mm at splice). The steel stress of B5 and B6 is about 87% and 79% 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 and reach the yield point. As shown in Figure 6.

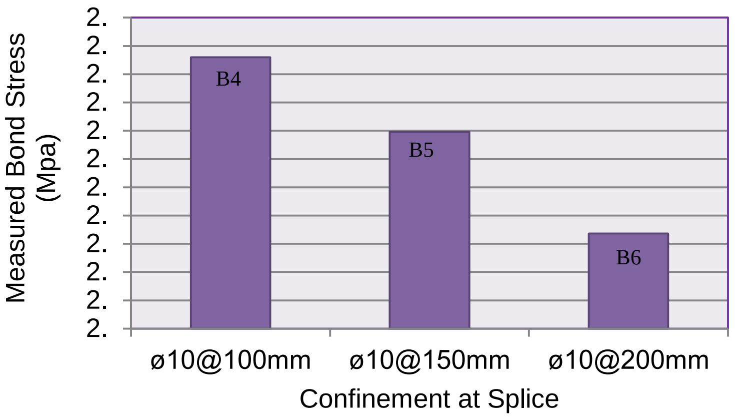


Figure 6: Bond stress for Group 2 (B4,B5,B6)

Influence of Concrete Cover

Load Capacity

It also noted that the cover (20mm) enabled the beam B1 to behave with amore ductility manner.Increase the concrete cover (decrease the effective depth) from (20mm to 50mm) increase significantly the max capacity and max deflection by 50% and 56% respectively. The specimens which have concrete cover (20mm) showed an increase in the energy absorption and ductility index and shear failure leads to decreasing in ductility and the energy absorption as shown in Figure7 and Figure 8.

Ductility Index and Energy absorption

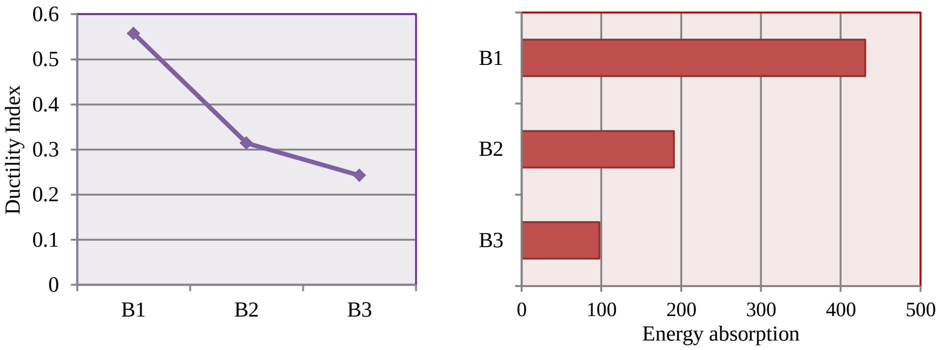


Figure 7: Ductility Index for Group1(B1,B2,B3)

Figure 8: Energy absorption for Group1(B1,B2,B3)

Stress Along Lap Splice and Bond Stress at Splice

The steel stress of B2 and B3 is about 93.4% and 39.6% of B1. The smaller steel stress of beams B3 in comparison to B1 can be attributed to the smaller cover of B1 than others, which enable this beam to exhibit larger steel stress before failure. From Figure 9 show that beam B1 had the maximum bond stress value , Which the bond stress of beams B2 and B3 is about 85% and 61% of B1 .Which means the affect of increasing concrete cover to decreasing the bond stress, Although the three beams had splice length equal to (50%Ld).

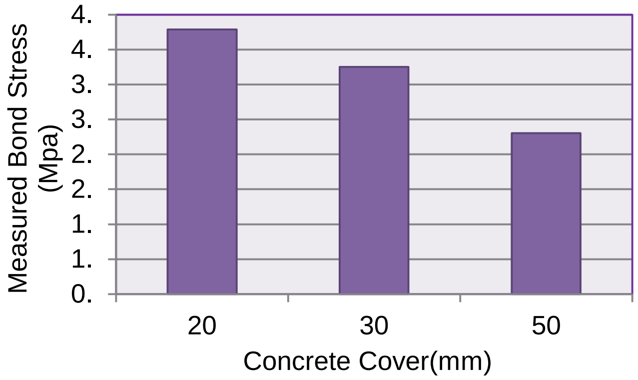


Figure 9 Bond Stress for Group 1 (B1,B2,B3)

Table 4 Results of tested beams.

Groups	(1)			(2)		
Beam ID	B1	B2	B3	B4	B5	B6
Bar diameter	12			12		
Type	SCC			SCC		
Fcu	35			35		
Cover	20	30	50	30		
Lap Splice	50%Ld			75%Ld		
Confinement	ø10@100mm			@100 mm	@150 mm	@200 mm
Cracking Load	35	35	25	35	35	30
Failure Load	150	120	75	160	151	125
Δmax	3.9	2.2	1.7	4.2	3.6	2.3
Ɛs Strain at failure*10^-3	2.4	2.06	1.46	2.72	2.56	2.335

Fs measured MPa	480	412	292	586	512	467
Mean Bond Stress (Mpa) (ACI-318)	3.7	3.2	2.3	2.18	2.04	1.86
Mode of Failure	shear		flexure	shear		

Conclusions

Based on the experimental and analytical results of 6 beams with cantilever specimens constructed from SCC with different lap splice configurations. The following conclusions can be drawn:

1 Increasing Splice length from (50%to 75%Ld) significantly improve the ductility, energy absorption and the structural behavior at failure (such as mode of failure), Splice length (75%Ld) have more ductility and energy absorption But it had a negative effect on the beam capacity .

2 Increasing stirrups intensity at splice zone from (ø10@200) to (ø10@100) mm decreases the shear cracks at the ends of splice and raise the capacity of specimens by 22% and make the failure more ductile, In order to the ductility and energy absorption increased by 45% and 63% respectively. Increasing stirrups intensity increases the ultimate bond stress by 14%.

3 Increasing concrete cover from (20) to (50) mm increases the cracks at splice and decrease the capacity of specimens and make the failure more brittle , as well as the bond strength was not great.

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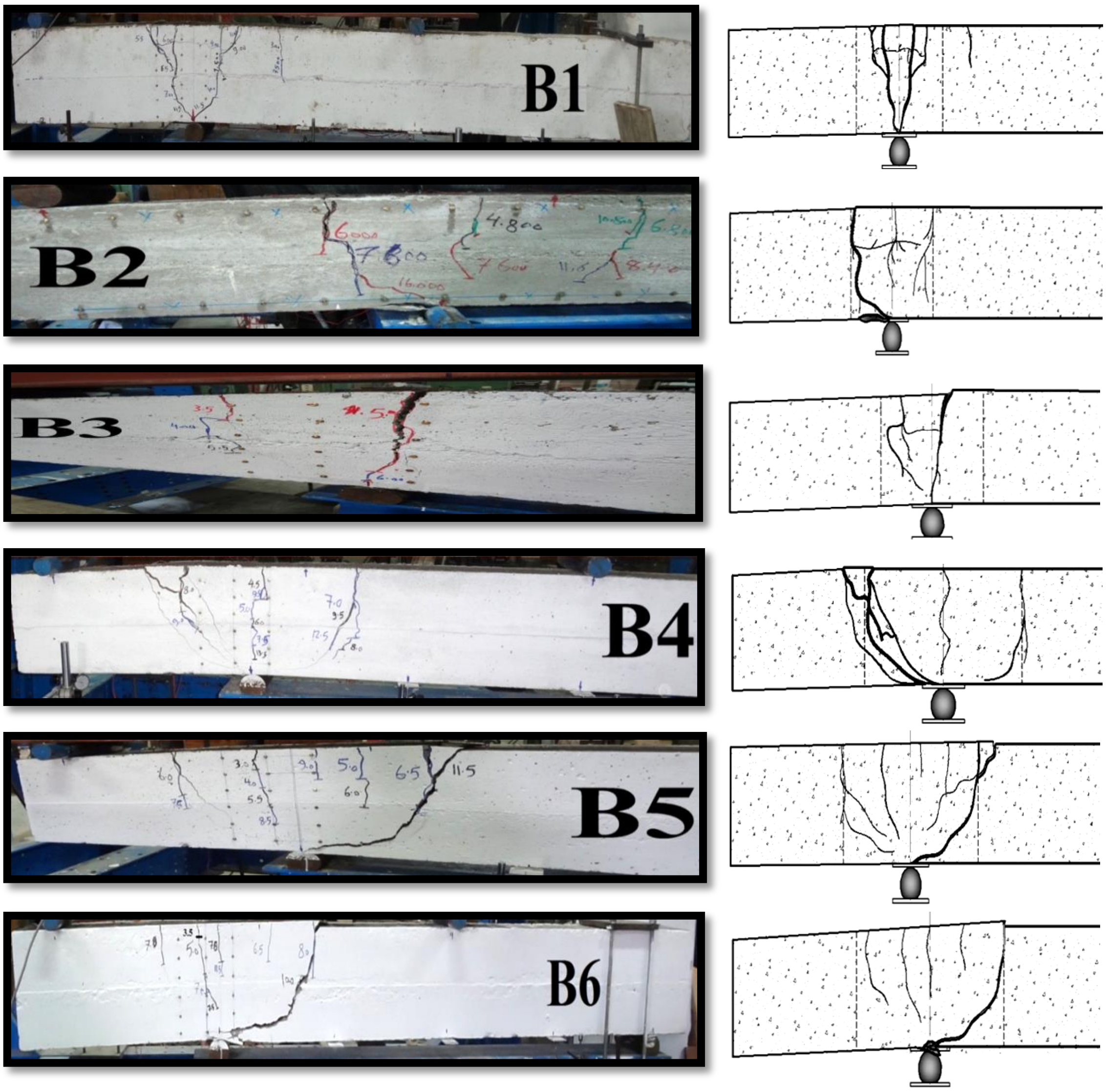

Figure 10 Crack patterns

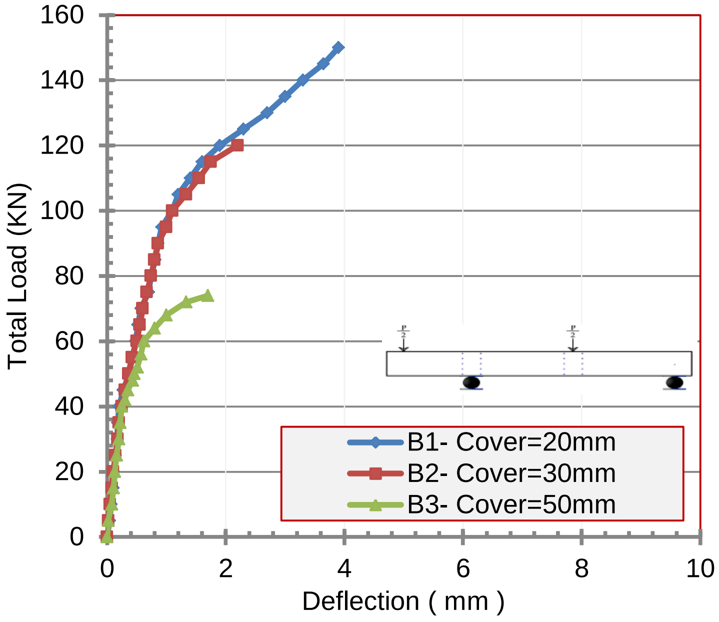

Figure 11 Group1(B1,B2,B3): Load-Deflection curve

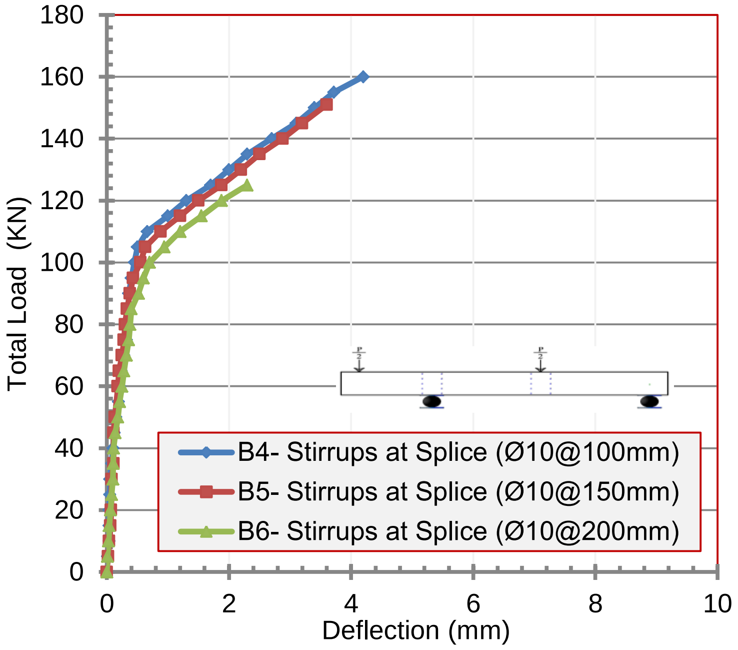

Figure 12 Group1(B4,B5,B6): Load-Deflection curve