Bond Behavior of Upper 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 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 major requirement for design of RC structures. The current study investigates the effect of various parameters that affect the bond behavior between SCC and steel rebars at the maximum shear strength zone such as: splice length, concrete cover and the effect of confining steel. The test results showed that increasing Splice length from (50%to 75%Ld) significantly improve the ductility, energy absorption and the structural behaviour at failure, increasing stirrups intensity at splice zone decreases the shear cracks at the ends of splice and raise the capacity of specimens and make the failure more ductile, increasing concrete cover increases the cracks at splice and decrease the capacity of specimens .**

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

1. INTRODUCTION

Bond between concrete and reinforcing bars in a splice is an important requirement for design of RC structures. Within the last 25 years, The Interest in SCC grows rapidly and now it's used in bridges and high-rise building construction. An example of SCC is the two anchorages of Akashi-Kaikyo Bridge which opened in 1998 and the bridge with the longest span in the world (1991 m). The bond between steel and concrete has direct influence on the behavior of reinforced elements in the cracked stage [19]. Deflections are affected by the distribution of bond stresses along the reinforcement bars and by the slip between the steel bar and concrete. Bond was the subject of many studies on SCC, but the conclusions were very contradictory: some mention that bond strengths of reinforcing bars in SCC are higher than those for NVC, others 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. Experimental work was done, and analytical equations were proposed by some researchers.

There have been several studies to make self-compacting concrete a standard one [9]. The subjects to be solved were summarized as, self-compactability testing method, mix-design including, acceptance testing method at site, and new type of powder or admixture suitable for SCC. The European Guidelines for SCC [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 recommendations have been provided using the wide range of experience and knowledge available to the European Project Group.

During the last decade, little researches were conducted on bond strength of self-compacting concrete [1–7]. In 1990, Atorod Azizinamini et al. [1] tested a total of 18 beam specimens with two or three bars spliced. The variables were (a) Concrete compressive strength f^{0}, (b) Splice length; and (c) Casting position. The results revealed 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 NVB, the top bar demonstrated^{c}approximately 8% reduction in bond capacity compared to bottom cast bars. As indicated by comparison with the results, top bars, as defined by the ACI 318-11 [10], produce higher bond capacity when HSC is utilized.

Yerlici and Ozturan [2] tesetd 53 eccentric pullout test specimens. Specimens were four groups, where a single parameter varied in each group. For the first three groups, the parameters were concrete compressive strength, the reinforcing bar diameter and thickness of 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 parameter of the fourth group was the percentage of web reinforcement that was made up of three closed stirrups spaced at 30 mm (1-3/16 in.), transversely crossing the anchorage length of the longitudinal bars. Web reinforcement varied from no stirrups to stirrups density of 3, 4, and 6 mm (D-1, D-2, and D-4) diameter steel bars. The results showed that the average anchorage bond strength varies with the compressive strength of concrete, as$(fc')^{2/3}$. ACI Code slightly underestimates the impact of concrete strength on anchorage bond resistance when applied on HSC, while it overestimates the effect of concrete cover on anchorage bond resistance when applied on HSC. The research project of Chan et al. [4] included the testing a RC wall as the pullout specimen where pullout reinforcing bars and transverse reinforcement were positioned, some walls were SCC while others were cast from NVC. The variables were; (a) Concrete compressive strength f^{0}, (b) Height of pull out bar (effect of top bar), and (c) Age of Concrete varied from 17 h to 28 days. It was concluded that SCC compared to NVC exhibits higher bond to reinforcing rebars and lower reduction in bond strength due to the top-rebar effect. The slow improvement of concrete compressive strength and bond strength in SCC at early ages is due to the retarding effect of the carboxylic high-range water-reducing admixture used. Almeida et al. [5] tested 66 beam specimens made from 3 SCC mixes. The variables were (a) Maximum aggregate size, and (b) SCC fluidity. It was found that the bond resistance was not affected by the SCC lack of fluidity. It was also found that high strength concretes have a fragile rupture of the bond connection. Also, unless some confinement reinforcement is provided, splitting of concrete surrounding the bar will happen as the concrete tension strength is attained. 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 beam specimens (2000 *300 *200 mm) were tested at positive bending [6] loading system was done to determine the effect of SCC and reinforcement diameter on bond–slip characteristics of tension lap-slices. The beams of lap-splice group were tested with lap-spliced bars in the midspan at a region of constant positive bending. The results showed that load transfer within the tension lap-spliced bars in SCC in a RC beam was better than that of the tension lap-spliced bars in NVC. The SCC beam specimens had generally longer cracks in length than the beams produced from NVC regardless of the reinforcing bar diameter. The project of Cattaneo and Rosati [7] included testing of 27 pullout specimens containing one embedded reinforcement bar. The variables were reinforcement bar diameter, fiber existence and confinement. Two types of tests were done: unconfined and confined pullout. The tests showed a remarkable size effect on bond strength, smaller bar diameter exhibited a higher strength than the bigger one. The bond strength of SCC 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 splitting failure in SCC.

2. EXPERIMENTAL WORK

Six full-scale simply supported beams with cantilever specimens were tested with different configurations under two-point loads. The main objective of the test program is to investigate the effect of the main parameters.

2.1 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 discusses the behavior of bond in shear failure at support at 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	
Grup 2	B4					100		30	75% Ld
	B5					150			
	B6					200			

2.2 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 NVC mixes. These aspects should therefore be considered during designing and specifying SCC. Current knowledge of those aspects is limited, and this can be a region requiring further research. We must 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 characterized 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 characterized 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
Lime Stone Powder	112.5

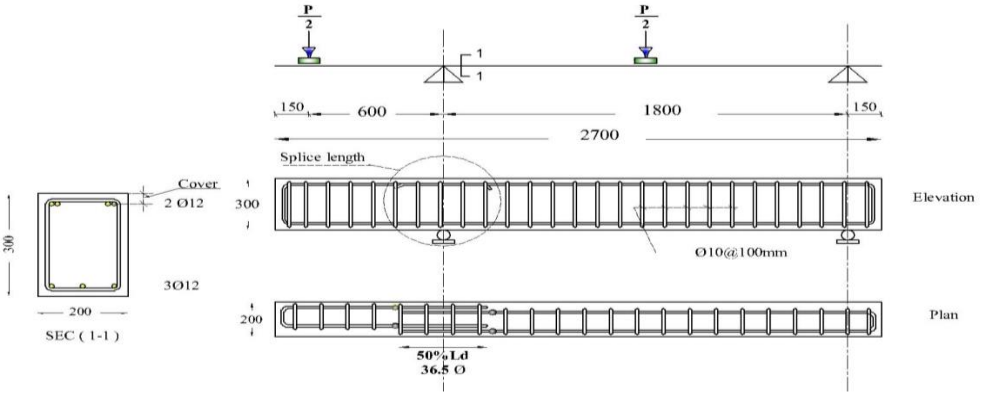
High performance super-plasticizer concrete admixture (Viscocrete-3425) used.

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
Is there segregation of aggregates?		NO

2.3 Test procedure

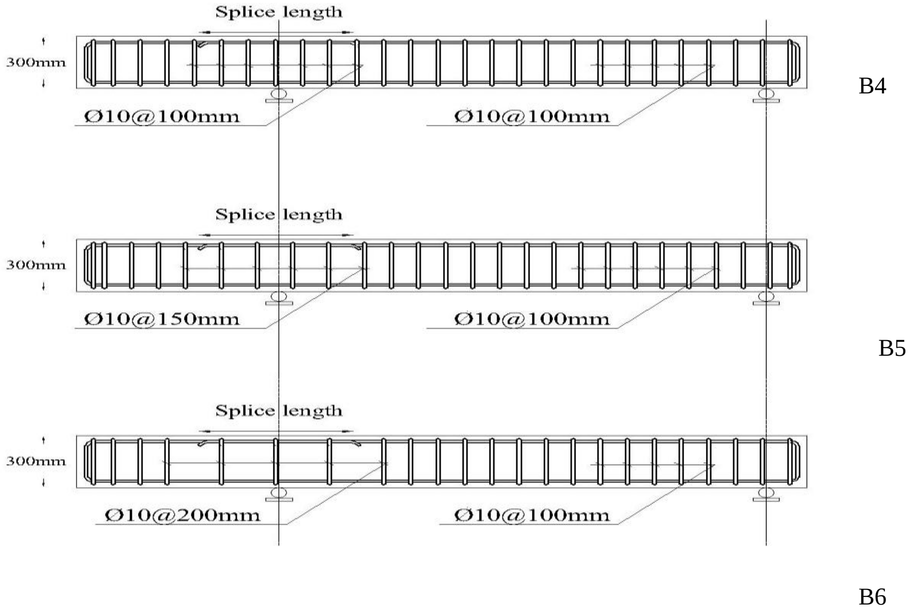
Specimens used in this research consisted of two groups, 6 R-section self-compacting beams. All beams have a total depth 300 mm, width 200 mm and length of specimens 2700 mm. Figure 1 and Figure 2 show the geometry and dimensions of the tested specimens.



All dimensions in mm., Beams cover (B1=20mm, B2=30mm, B3=50mm)

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

75%Ld=55Φ



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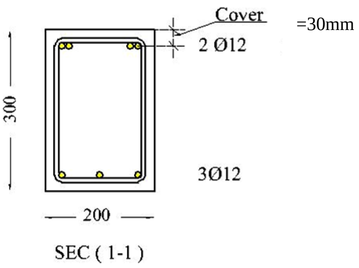

Figure 2: Geometry and Dimensions of Group 2 (B4, B5, B6)

2.4 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.

2.5 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.

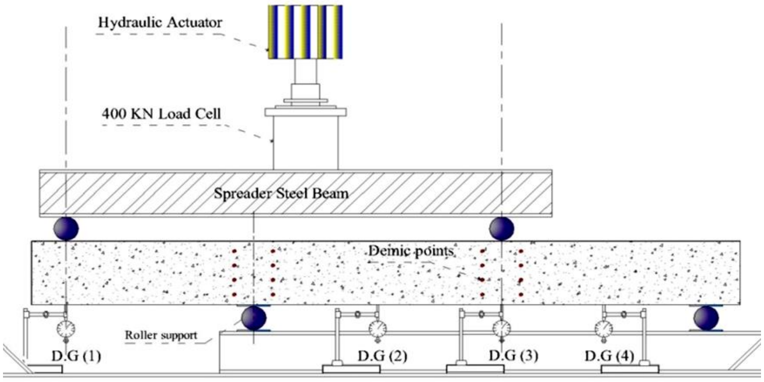

Figure 3: Test setup

3. TEST RESULTS

Table 4 shows results of beams and Figure 4 shows crack pattern of the tested beams

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	@200mm
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
Ƹs 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		

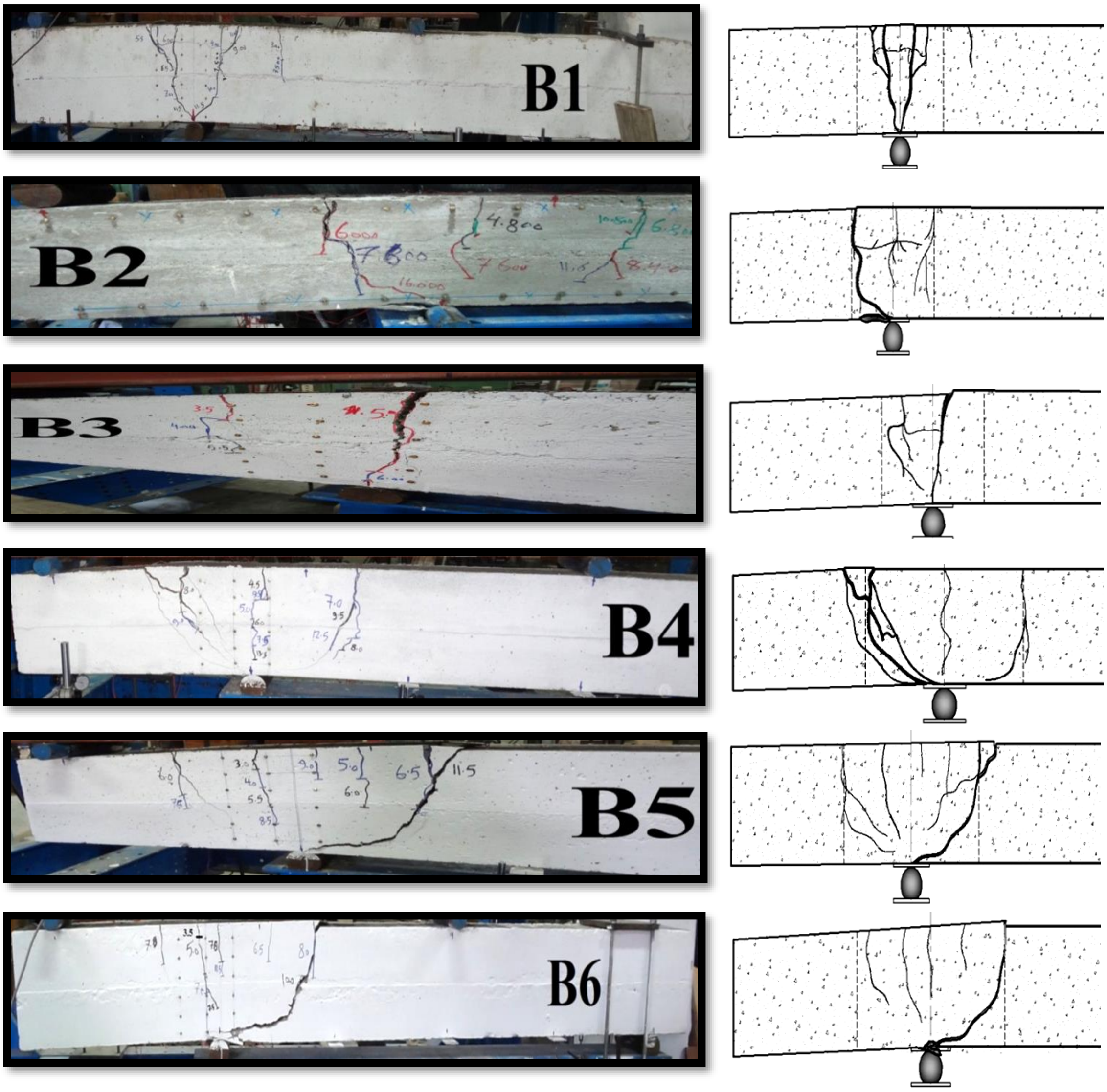

Figure 4: Crack patterns of specimens

3.1 Influence of Confinement at Splice

3.1.1 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 Figure 5 , 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[20] where they stated that stirrups eliminate the sudden and violent failure. Also, these results match with Ralejs [21] results who stated that stirrups prevent the sudden disruption of equilibrium at splice zones.

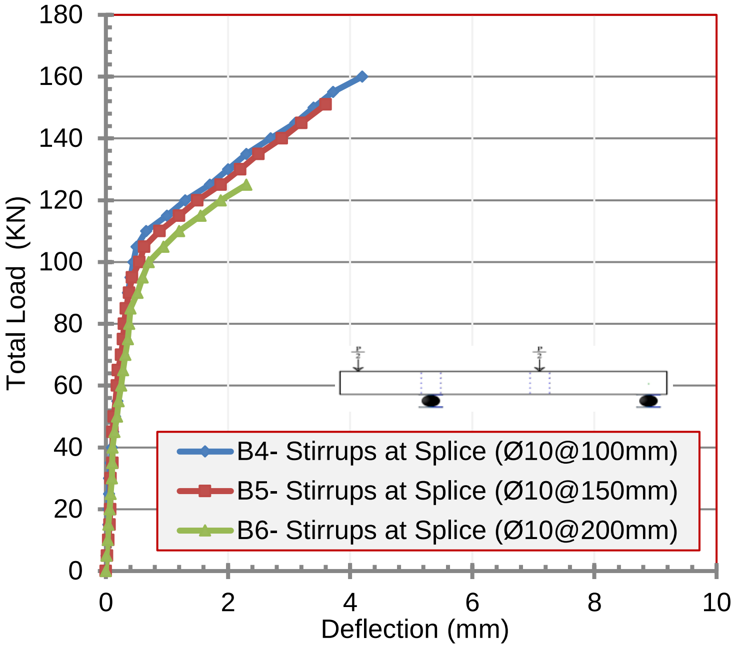

Figure 5: Group1(B4, B5, B6): Load-Deflection curve

3.1.2 Energy absorption

Figure 6 shows that the energy absorption decreases with increasing the spacing between stirrups at the lap splice, Decreasing confinement at splice zone from ø10@100 mm. to ø10@200 mm. decreased the E.A to 62% according to beam B4.

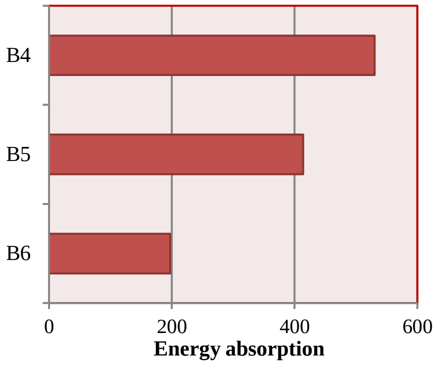

Figure 6: Energy absorption for Group 2

3.1.3 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 (586MPa) 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. From Figure 7 shows that beam B4 had the maximum bond stress value , Which the bond stress of beams B5 and B6 is about 93% and 85% of B1 .Which means that increasing confinement increases bond stress, Although the three beams had same splice length equal to (75%Ld).

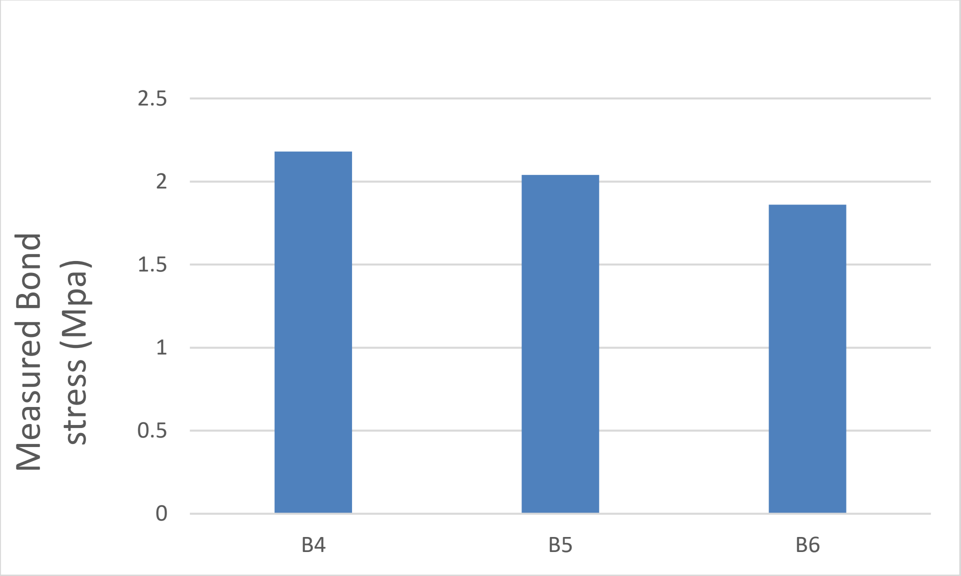

Figure 7: Bond stress for Group 2 (B4, B5, B6)

3.2 Influence of Concrete Cover

3.2.1 Load Capacity

The recorded ultimate load of beam B2 and B3 was about 80% and 50% of B4, it can be attributed to that increasing the concrete cover decrease the effective depth from (20mm to 50mm) which led to decreasing the failure load.

It was noted that the cover (20mm) enabled the beam B1 to behave with a more ductility manner. Increase the concrete cover from (20mm to 50mm) increase significantly the max capacity and max deflection by 50% and 56% respectively as shown in Figure 8.

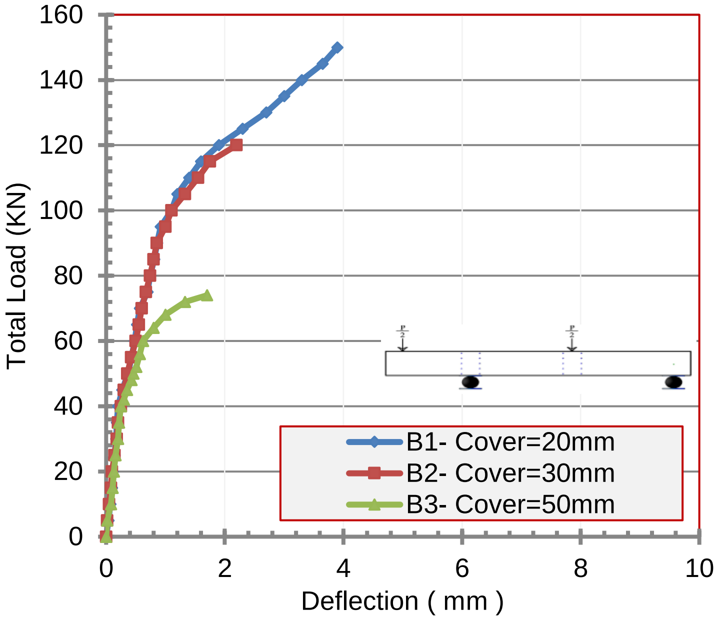

Figure 8: Group1(B1,B2,B3) Load-Deflection curve

3.2.2 Energy absorption

Figure 9 shows that the energy absorption decreases with increasing the concrete cover, increasing concrete cover form 20 to 50 mm. decreased the E.A to 76% according to beam B1.

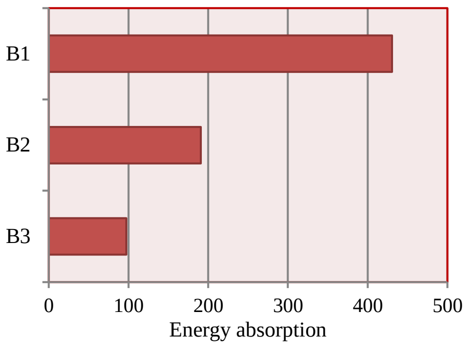

Figure 9: Energy absorption for Group1(B1, B2, B3)

3.2.3 Stress Along Lap Splice and Bond Stress at Splice

The steel stress was affected by concrete cover, where the maximum steel stress was (480MPa) of B1 (with cover 20mm.). The steel stress of B2 and B3 is about 85% and 60% 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 10 shows that beam B1 had the maximum bond stress value , Which the bond stress of beams B2 and B3 is about 86% and 62% of B1 .Which means that increasing concrete cover decreases the bond stress, Although the three beams had splice length equal to (50%Ld).

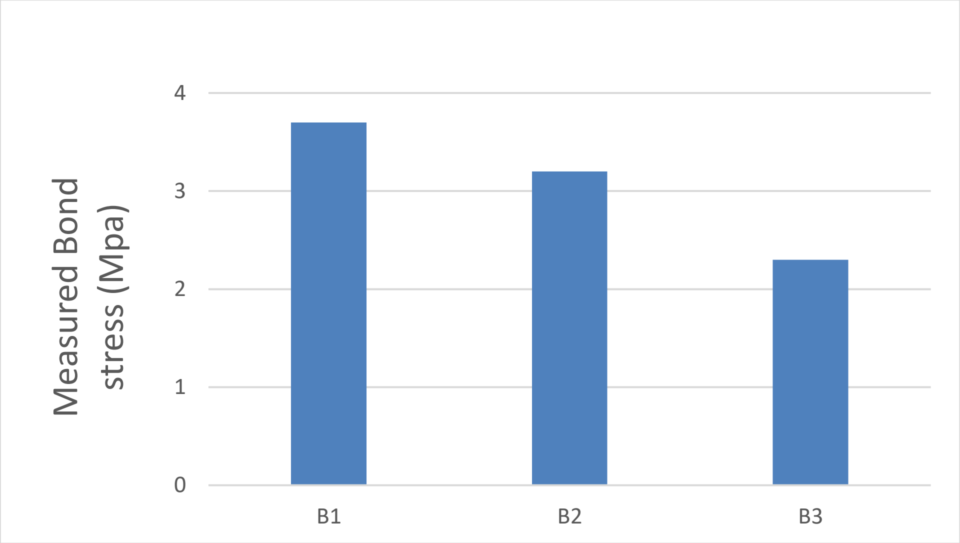

Figure 10: Bond Stress for Group 1 (B1, B2, B3)

3.3 Influence of Lap Length in SCC Beams:

3.3.1 Load Capacity

The recorded ultimate load of beam B2 was about 80% of B4, it can be attributed to that increasing splice length led to increasing the failure load.

The smaller ductility of B2 compared with that of beam B4 is due to the smaller ultimate load of B2, the beam B2 had lower deflection than beam B4.Which can be stated that the beam (with splice75% Ld) enable the beam to more ductile manner and enable beam to improving the moment capacity

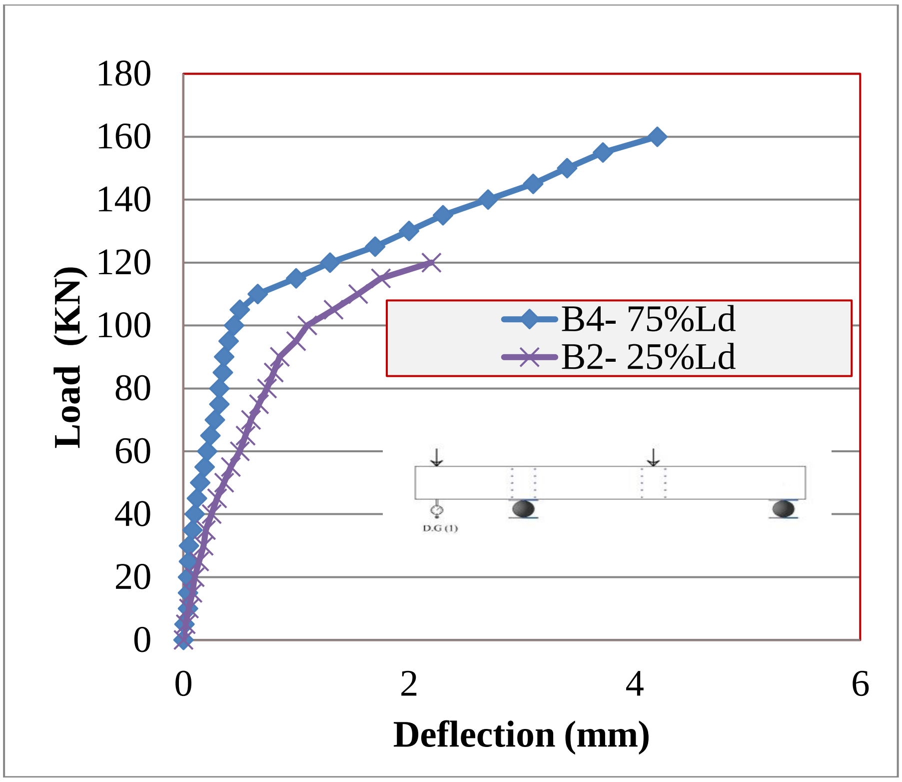

Figure 11: load-deflection curve for Beams (B2, B4)

3.3.2 Energy absorption

Figure 12 shows that the energy absorption decreases with decreasing the splice length from 75 to 25% Ld. decreased the E.A to 64% according to beam B4.

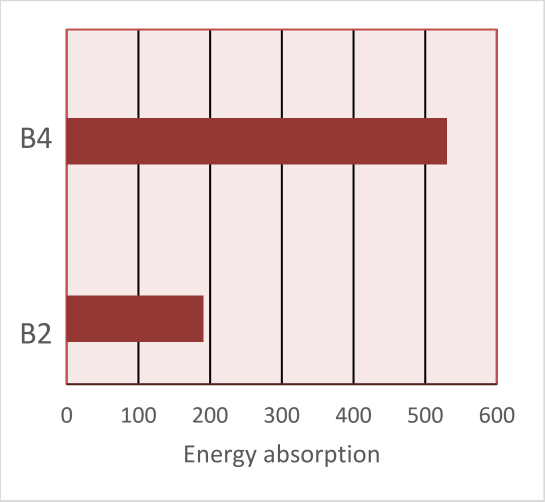

Figure 12: Energy absorption for Specimens B2 & B4

4. 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 was drawn:

1 Increasing Splice length from (50%to 75%Ld) significantly improve failure load, ductility, energy absorption and the structural behaviour at failure (such as mode of failure), Splice length (75%Ld) have more ductility and energy absorption.

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, 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 good.

REFERENCES

[1] Azizinamini, A., Stark, M., Roller, J. J., & Ghosh, S. K. (1993). Bond performance of reinforcing bars embedded in high-strength concrete. *Structural Journal*, *90*(5), 554-561.
[2] Yerlici, V. A., & Ozturan, T. (2000). Factors affecting anchorage bond strength in high-performance concrete. *Structural Journal*, *97*(3), 499-507.
[3] Goodier, C. I. (2003). Development of self-compacting concrete.
[4] Chan, Y. W., Chen, Y. S., & Liu, Y. S. (2003). Development of bond strength of reinforcement steel in self-consolidating concrete. *Structural Journal*, *100*(4), 490-498.
[5] Valcuende, M., & Parra, C. (2009). Bond behaviour of reinforcement in self-compacting concretes. *Construction and Building Materials*, *23*(1), 162-170.
[6] Turk, K., Benli, A., & Calayir, Y. (2008). Bond strength of tension lap-splices in full scale self-compacting concrete beams. *Turkish J. Eng. Env. Sci*, *32*, 377-386.
[7] Cattaneo, S., & Rosati, G. (2009). Bond between steel and self-consolidating concrete: experiments and modeling. *ACI Structural Journal*, *106*(4), 540.
[8] El-Azab, M. A., Mohamed, H. M., & Farahat, A. (2014). Effect of tension lap splice on the behavior of high strength self-compacted concrete beams. *Alexandria Engineering Journal*, *53*(2), 319-328.
[9] ACI Committee, & International Organization for Standardization. (2008). Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute.
[10]] ACI Committee 408 (2003). Bond and Development of Straight Reinforcing Bars in Tension (ACI408R-03), American Concrete Institute, Farmington Hills, Michigan, USA.
[11] Zuo, J. and Darwin, D. (2000). "Splice strength of conventional and high relative rib area bars in normal and high-strength concrete", ACI Structural Journal, Vol. 97, No. 4, pp. 630–641.
[12] Hassan, T., Seliem, H., Dwairi, H., Rizkalla, S. and Zia, P. (2008)."Shear behavior of large concrete beams reinforced with highstrength steel", ACI Structural Journal, Vol. 105, No. 2, pp. 173–179.
[13] Orangin, C.O., Jirsa, J.O. and Breen, J.E. (1977). "A reevaluation of test data on development length and splices", ACI Journal Proceedings, Vol. 74, No. 3, pp. 114–122.
[14] Darwin, D., Tholen, M.L., Idun, E.K. and Zuo, J. (1996). "Splice strength of high relative rib area reinforcing bars", ACI Structural Journal, Vol. 93, No. 1, pp. 95–107.
[15] Esfahani, M.R. and Rangan, B.V. (1998). "Local bond strength of reinforcing bars in normal strength and high-strength concrete (HSC)", ACI Structural Journal, Vol. 95, No. 2, pp. 96–106.
[16] European Guidelines for Self-Compacting Concrete, specification, production and use / BIBM, CEMUREAU, EFCA, EFNARC, ERMCO // May 2005.
[17] Specification and Guidelines for Self-Compacting Concrete / EFNARC // February 2002. G. De Shutter /Guidelines for testing fresh Self-Compacting Concrete // September 2005.
[18] Chan, Y.W.; Chen, Y.S. and Liu, Y.S., "Development of Bond Strength of Reinforced Steel in Self-Consolidating Concrete", ACI Structural Journal, V.100, No.4, Jul.-Aug.2003, pp.490-498.
[19] Schiessl, A. and Zilch, K., "The Effects of the Modified Composition of SCC on Shear and Bond Behavior", Proceedings of Second International Symposium on Self Compacting Concrete, K. Ozawa and M. Ouchi, eds., Tokyo, Oct.2001, pp.501-506.
[20] Ferguson, P.M. and Breen, J.E., 1965, September. Lapped splices for high strength reinforcing bars. In *Journal Proceedings* (Vol. 62, No. 9, pp. 1063-1078).
[21] Tepfers, R., 1979. Cracking of concrete cover along anchored deformed reinforcing bars. *Magazine of concrete research*, *31*(106), pp.3-12.