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Influence of Fusion Bonded Epoxy Coated Bars on Tension Stiffening Of Self Compacting Concrete

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Abstract: *This paper presents the results of an experimental study on the tension stiffening response of fusion bonded epoxy coated bars embedded in self compacting concrete (SCC). 18 numbers of direct tension specimens recommended by RILEM standards are used with modified specimen lengths of 40 and 50 times the diameter of the bar. From the study it is concluded that fusion bonded epoxy coating on bars has a negative effect on the tension stiffening of SCC. The reduction ranges from 9.4 % to 32% .The tension stiffening effect improves to an extent of 20-30 % as bar diameter is reduced from 12 mm to 10 mm. Spacing of cracks is 7-18% more if fusion bonded epoxy coated bars are used in SCC.*

Keyword: *Self compacting Concrete, Fusion bonded Epoxy coated bars, Tension stiffening effect(TSE) , Direct tension test, Corrosion, Packing density, cracking*

I. Introduction

Tension Stiffening in reinforced concrete increases the stiffness of a cracked member due to the development of tensile stresses in the concrete between the cracks. In other words, the reduction in strain of reinforcement due to tensile stresses in concrete between cracks is termed as “Tension Stiffening”. Before cracking, the concrete tensile stress increases with load. When the stress in the concrete first reaches the tensile strength at a particular section, cracking occurs, Figure 1(a). When cracking occurs, the stress in the concrete at the crack, drops to zero. The concrete stress increases with distance from the crack, due to the steel-concrete bond, until at some distance from the crack, the concrete stress is no longer affected by the crack, as shown in Figure 1(b). Slip at the concrete-steel interface in the region of significant bond stress causes the crack to open. The concrete stress increases with distance from the crack, due to the steel-concrete bond, offering some resistance to the applied load, which is the ‘Tension Stiffening’ effect in concrete.

The parameters affecting tension stiffening in concrete are concrete cover thickness, concrete spacing, bar diameter, longitudinal splitting and yielding of reinforcement [1]. The number and spacing of visible cracks are more or less proportional to the thickness of concrete cover. There is a small tendency to a proportional lower tension stiffening effect for larger sizes. Longitudinal splitting cracks occur close to the yielding of reinforcement. The smaller the cover concrete, the larger the reduction in tension stiffening of concrete is predicted [2]. The crack width increased about 16% when the concrete cover provided is doubled. The changes in the crack width can be predicted only up to a cover of 65 mm. It is argued that decrease in the crack width caused by using higher reinforcement ratios has been, at least by part, compensated by an increase in the crack width resulted from using larger diameter bars [3]. An increase in the tension stiffening behavior with decrease in reinforcement ratio and increase in concrete strength was observed. No appreciable change in tension stiffening was recorded with changes in bar diameter at constant reinforcement ratio [4]. The interaction of structural steel reinforcement and high-performance fiber-reinforced cement composites (HPFRCC) in uni-axial tension is studied. The effects of cementitious composite ductility on the steel reinforced composite deformation behavior are experimentally investigated and contrasted to conventional reinforced concrete. The engineered cementitious composite are capable of taking more load when compared to that of the ordinary reinforced member. As the load carrying capacity of engineered cementitious composite is increased the formation of cracks in these members will be decreased due to the transfer of stress between the cracks. There is an increase in the tension stiffening effect in an engineered cementitious composite is recorded[5]. Hamed Salem et al investigated the influence of concrete over on the tension stiffening effect in concrete. Three specimens based on Abrishami and Mitchell model with the same reinforcement ratio and different cover thickness of 40mm(1.57inch), 10 mm (0.39inch) and 5 mm(0.19inch) were made. A single rod of 10 mm(0.39inch)diameter is centrally placed in the specimen. For the 40 mm(1.57inch) cover specimen, the model predicts no splitting cracks and three transverse cracks over the length. For 10 mm(0.39inch) cover specimen, analysis predicts splitting cracks with only one transverse crack, while for the 5 mm(0.19inch) cover specimen no transverse crack is expected and the longitudinal cracks are predicted in analysis. The tension stiffening is affected by the longitudinal cracks and the corresponding reduction of bond stresses. The smaller the cover concrete, the larger the reduction in tension stiffening of concrete is predicted[6]. H. Narendra et al investigated the serviceability criteria to ensure satisfactory prediction behavior of the structural members subjected to loads. The beams with shallow depth undergo larger deflection than the specified limits, where the effect of tension stiffening is unnoticed. The prediction made with ignorance of tension stiffening effect leads to greater deflection which will cause unnecessary ponding effect[7]. Homayoun H et al investigated the influence of splitting cracks on tension stiffening of reinforced concrete members. The diameter of bars and the strength of the concrete were varied. It was concluded that development of transverse cracks reduces the tension stiffening, the presence of longitudinal splitting cracks was found to significantly alter the tension stiffening. It is also found that the concrete cover to bar diameter ratio provides a useful indicator for determining the extent of concrete splitting with a decrease in the cover to diameter ratio results in more significant splitting cracks. As the splitting cracks are more significant, the tension stiffening effect decreases[8]. Yuichi et al investigated the tension stiffening effect with Fiber reinforced polymer sheets. They concluded that tension stiffening effect of Fiber reinforced polymer is independent on the cross sectional area of the concrete because the stiffness of fiber reinforced polymer sheet is usually negligible related to that of concrete[9].

II. Research Significance

The resistance of concrete in tension to the applied load due to bond between steel and concrete is called “Tension Stiffening Effect”. This contribution of concrete has been evaluated and reported extensively in literature for normal vibrated concrete. However, there is a lack of knowledge on the contribution of Self compacting concrete to Tension Stiffening Effect. Furthermore, fusion bonded epoxy coated bars are most popularly used with Self compacting concrete in bridge construction and high rise buildings. Hence, there is a need is to investigate the tension stiffening effect in self compacting concrete using epoxy coated bars. Moreover, RILEM standard specifies that the length of the specimen to be used for determination of the tension stiffening effect is 60 times the diameter of bar. As this would result in very long specimens, it was decided to investigate whether a shorter specimen of length equal to 40 or 50 times the diameter of bar would serve the purpose.

Materials Used

Ordinary Portland cement of 43 grade confirming to IS 4031-1988whose compressive strength at the end of 28th day is 45N/mm^2(6526.69psi). Locally available sand conforming to Zone II is used in this experimental work. The chemical composition of river sand is determined as per IS 2386 (Part-III)-1963. Locally available crushed granite coarse aggregate is used. Class F fly ash from Ennore Thermal Plant is used. The main reason for incorporating Class F fly ash is that this fly ash contains 70% of pozzalonic materials. Super plasticizer Varaplast SP 123 is used for attaining the required flow characteristics. Three reinforcing steel bars of 8 mm (0.31inch) diameter, 10 mm (0.39inch) diameter and12 mm (0.47inch) diameter coated and uncoated are used. Uncoated bars of 8 mm (0.31inch), 10 mm (0.39inch) and 12 mm (0.47inch) have a yield stress of bars about 416 N/mm^2 (60335.8psi), 428 N/mm^2(62076.1psi) and 448N/mm^2 (63236.4psi) respectively. Epoxy coated bars which are used has coating thickness at the range of 0.1mm (.0039inch) to 0.3mm (.0118inch), with the same yield stress as that of uncoated bars.

Proportioning And Properties Of Self Compacting Concrete

Packing density is the ratio of tightly packed aggregate to loosely pack aggregate. A higher Packing Factor, indicate greater amount of aggregate content, which will require less binder and generally will have less flow ability and vice-versa. The aggregate Packing Factor determines the aggregate content and influence the strength, flow ability and self–consolidation ability for the self-compacting concrete [10].The proposed procedure consists of optimization of paste, aggregate and concrete phases. Strength and workability are obtained based on concept of particle packing and theology [11]. The basic principle of the mix design is to maximize the packing density of the ingredients to get enhanced fresh and hardened properties of SCC. The optimization of aggregate was determined experimentally, using a modified version of the test procedure described in ASTM C 29[12]. The packing density of the aggregates was calculated from the void content. Geometrical characteristics of material such as shape, angularity, texture, particle size distribution (PSD), wall effect and method of compaction are collectively referred as packing density. If packing density is more, there will be less voids and hence less paste is sufficient to fill the voids and the remaining paste is used for the flow ability of concrete. The remaining paste is used for the flow of concrete. Based on the general trials made, it is found that fine aggregate: coarse aggregate 25 mm (.98 inch): coarse aggregate 12.5 mm (.49inch) is 40:30:30 obtaining the maximum packing density. The optimization of the powder is obtained using Punted test. Punted test considers the saturation point of the mixture of cement and fly ash. The saturation point is indicated as the excess water coming out after filling the voids which results in maximum packing density. Various power combinations are conducted and 60:40 (cement: fly ash class F) ratio obtains the maximum packing density. The optimization of SP dosage can be obtained using mini-slump test. This test considers the bleeding of cementitious material and flow obtained using SP in cement. A value of 0.2% of cementitious material is the required amount of SP dosage [13]. The necessity of VMA dosage can be obtained by the sieve segregation test. If the degree of segregation from the test is more than 15%, use of VMA is recommended. The test indicated the test result to be less than 15%. So VMA is not used in this work. If the segregation degree is more than required, marble test is used to optimize the dosage of VMA [14].The mix proportion based on the packing density method is shown in Table 1.The workability of SCC can be obtained using slump test, J test. Slump test assess the filling ability of the fresh mix. It measures two parameters: flow spread and flow time T50. The diameter of the spread of the sample is measured. The J-ring flow spread indicates the restricted deformability of SCC due to blocking effect of reinforcement bars. The workability of the mix proportion is shown in Table 2.

Details of Specimen

Tension Specimens as per RILEM standards is used to determine the Tension stiffening effect. The cross section of the specimen is 100 x 100 mm and remains the same for all the samples. However, the length of the specimen is varied based on the diameter of the reinforcing bar embedded in the concrete. The length of specimen is fixed as 50 times the diameter or 40 times the diameter and the sizes are reported in Table 3.Table 3 also reports the diameter of bar, yield strength of steel fy and characteristic compressive strength of concrete fck used in this work.18 specimen was casted and cured for 28 days.

Experimental Set-Up And Testing Procedure

The testing of the specimens is carried out in universal testing machine of 1000 kN (225kilopounds) capacity. The specimens are to be fixed vertically between the movable and fixed jaw. About 75 mm (2.95inch) of each end of the steel bar are anchored and fixed in the grips of the jaw. The loading was continued till the yielding of the reinforcement. The deformation of the specimen was measured between two points at the center of the specimen as shown in Fig.2. This is found by fixing two LVDT's on either side of the specimens. The gauge length was 300 mm (11.81inch) for 8 mm (0.31inch) diameter specimens, 400 mm (15.71inch) for 10 mm (0.39inch) diameter specimens and 500 mm (19.68inch) for 12 mm (0.47inch) diameter specimens respectively. The graph between the stress and strain values are plotted and compared with the stress strain curve of the steel bar.

III. Results And Discussion:

Tension stiffening strain is defined as the difference in average strain in the specimen and reinforcing bar.The average force in steel is obtained from the measured strain. The average force in concrete is obtained by subtracting the force in steel from the total force applied to the specimen. Fig.3 and Fig.4 shows the stress strain curves for with or without concrete. The tension stiffening strain is calculated from these curves and tabulated in Table 4 and Table 5.

Influence Of Coating On Tension Stiffening

From table 4, it is found that in case of 12 mm (0.47inch) bars with specimen length equal to 50 times diameter, the tension stiffening strain at 33.9kN (7620pounds) applied load is 23×10^{-4} and $20 X 10^{-4}$ for uncoated and coated bars respectively. In case of 12 mm (0.47inch) bars with specimen length equal to 40 times diameter, the tension stiffening strain at 45.2kN (10160.96pounds) applied load is 56×10^{-4} and $38 X 10^{-4}$ for uncoated and coated bars respectively. From table 5, it is found that in case of 10 mm (0.39inch) bars with specimen length equal to 50 times diameter, the tension stiffening strain at 45.2kN(10160.96pounds) applied load is 42×10^{-4} and $38 X 10^{-4}$ for uncoated and coated bars respectively. In case of 10 mm (0.39inch) bars with specimen length equal to 40 times diameter, the tension stiffening strain at 45.2kN (10160.96pounds) applied load is 43×10^{-4} and $38 X 10^{-4}$ for uncoated and coated bars respectively. From the above observation, it is found that the tension stiffening effect is more in uncoated bars than coated bars irrespective of bar diameter and length of specimen. The effect of coating is 13% to 32% in 12 mm (0.47inch) bars and 9.4% in 10 mm (0.39inch) bars for specimen of 50 times diameter and 40 times diameter irrespective of specimen length.

Influence Of Bar Size On Tension Stiffening

From table 4 and table 5, it is found that in case of uncoated bars with specimen length equal to 50 times diameter, the tension stiffening strain at 11.3kN (2540pounds) and 31.4kN (7058 pounds) applied load is 9×10^{-4} and $42 X 10^{-4}$ for 12 mm (0.47inch) and 10 mm (0.39inch) bars respectively. In case of uncoated bars with specimen length equal to 40 times diameter, the tension stiffening strain at 31.4kN(7058 pounds) and 33.9kN (7620pounds) applied load is 43×10^{-4} and $30 X 10^{-4}$ for 10 mm (0.39inch) and 12 mm (0.47inch) bars respectively. In case of coated bars with specimen length equal to 50 times diameter, the tension stiffening strain at 23.5kN (5282pounds) and 22.6kN (5080pounds) applied load is 26×10^{-4} and $19 X 10^{-4}$ for 10 mm (0.39inch) and 12 mm (0.47inch) bars respectively. In case of coated bars with specimen length equal to 40 times diameter, the tension stiffening strain at 31.4kN (7058 pounds) and 33.9kN(7620pounds) applied load is 39 x 10^{-4} and 31 X 10^{-4} for 10 mm (0.39inch) and 12 mm (0.47inch) bars respectively. From the above observation, it is found that the tension stiffening effect is more in 10 mm (0.39inch) bar than 12 mm (0.47inch) bar. The tension stiffening in 10 mm (0.39inch) is 20%-30% more than 12 mm (0.47inch) bar irrespective of coating and specimen length.

Cracking Response Of SCC In Tension

The first cracking loads and the mean crack spacing for self compacting concrete specimens are reported in Table 6. It is evident from the table that irrespective of bar diameter, crack spacing increases as specimen length decreases. Further, spacing of crack is 7% -18% more in coated bars. Although cracking of concrete is inevitable, it is desirable to aim for a large number of well-distributed fine hairline cracks, rather than few but wide cracks. This is the objective of limit state design for the serviceability. More the spacing of cracks, brittle is the behavior of reinforced concrete and more crack spacing in concrete reinforced with coated bars is more and is an indication of brittle failure as compared to RC with uncoated bar. The first crack in 12 mm (0.47inch) specimens is formed at a load of 30kN irrespective of the specimen length and coating to the bars. However, there is an influence of coating and specimen length in 10 mm (0.39inch) bars.

IV. Conclusions

An experimental study to determine Tension stiffening effect in Self compacting concrete has been presented. Based on the results, the following conclusions are drawn:

1. Fusion bonded epoxy coating on bars has a negative effect on the tension stiffening of SCC. The tension stiffening effect reduces in coated bars of 12 mm diameter. The reduction is 13% and 32% for specimen of 50 times diameter length and 40 times diameter length respectively. In 10 mm bars the reduction in tension stiffening effect is 9.4% irrespective of specimen length.
2. The tension stiffening effect improves as bar diameter is reduced from 12 mm to 10 mm. The improvement is 20%-30% .
3. Spacing of cracks is more in fusion bonded epoxy coated bars and is 7% -18% more than uncoated bars .
4. If smaller bar diameters are used in SCC,The load at first crack in influenced by coating and specimen length

Acknowledgments

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Notations

Φ – Diameter of bar
TSE – Tension Stiffening Effect

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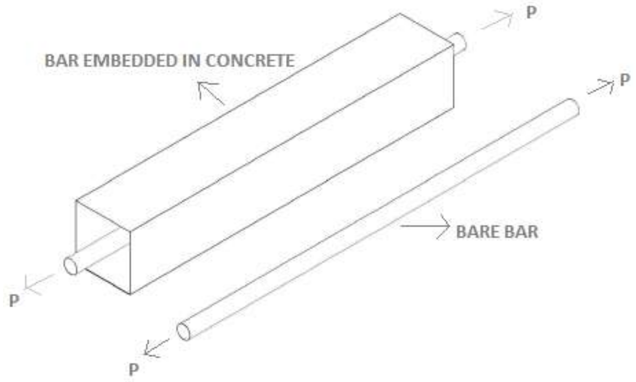
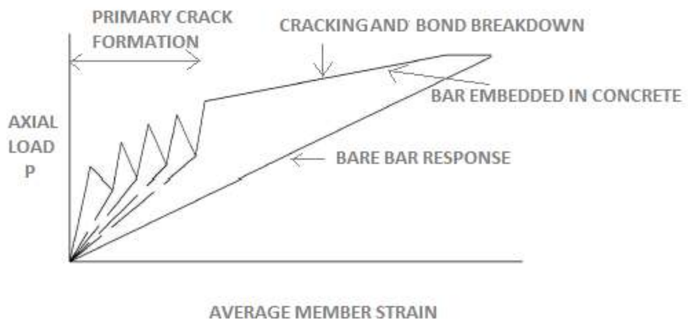


(a) RILEM specimen used to determine tension stiffening effect of concrete



(b) AXIAL LOAD VS AVERAGE AXIAL STRAIN RESPONSE

Figure 1 Tension stiffening in an axially loaded tension member

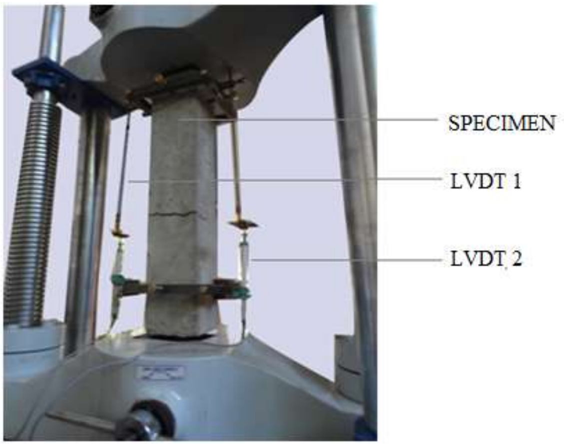


Figure 2 Experimental setup

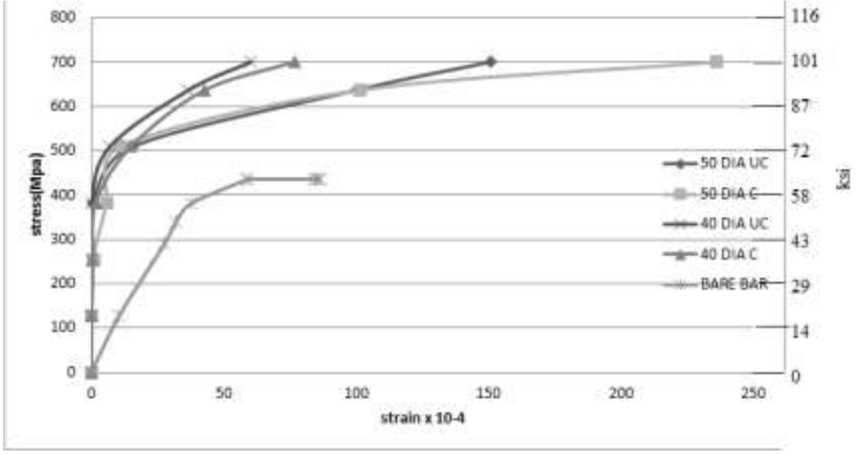


Figure 3 Tension Stiffening response of SCC for 10 mm(0.39inch) specimen

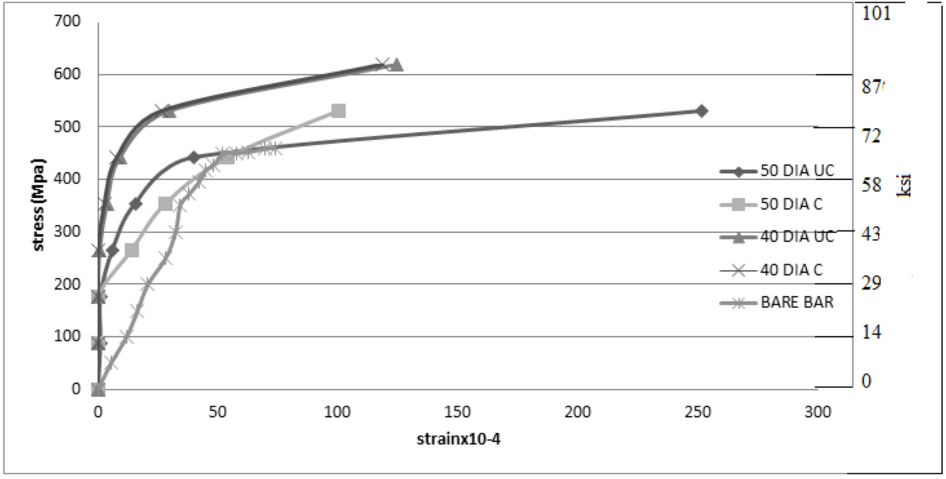


Figure 4 Tension Stiffening response of SCC for 12 mm (.47inch) specimen

Table 1 Proportions of SCC

S.No	Materials	Quantity
1	Cement	22lb/ft^3(353kg/m^3)
2	Fly ash	9.6lb/ft^3 (155kg/m^3)
3	Fine aggregate	58 lb/ft^3 (628kg/m^3)
4	Coarse aggregate-20 mm(0.78inch)	30.2 lb/ft^3(485kg/m^3)
5	Coarse aggregate-12.5 mm(.49inch)	30 lb/ft^3 (480kg/m^3)
6	Water	13 lb/ft^3 (209lit/m^3)
7	Super Plasticizer	1lit/m^3

Table 2 Properties of fresh self compacting concrete

Test conducted	**Value Attained**	**Permissible range**
Slump Flow	590 mm (23.22inch)	550 mm (21.65inch) to 850 mm (33.46inch)
T50 slump flow	4 secs	2 to 6 secs.
J ring	6 mm (.23inch)	0 to 10 mm (0.39inch)

Table 3 Details of the reinforced concrete tension specimens

Specimen Id *	**Diameter mm**	**Dimension of Specimen (mm)**	**fy MPa**	**fck MPa**
UC – 8	8 (0.31inch)	320 x 100 x 100	416 (60ksi)	46 (6.6ksi)
UC – 8	8 (0.31inch)	320 x 100 x 100	416 (60ksi)	46 (6.6ksi)
UC – 8	8 (0.31inch)	400 x 100 x 100	416 (60ksi)	47 (6.8ksi)
C – 8	8 (0.31inch)	400 x 100 x 100	416 (60ksi)	47 (6.8ksi)
C – 8	8 (0.31inch)	400x 100 x 100	416 (60ksi)	47 (6.8ksi)
C – 8	8 (0.31inch)	400x 100 x 100	416 (60ksi)	47 (6.8ksi)
UC – 10	10 (0.39inch)	400x 100 x 100	428 (62ksi)	50 (7.2ksi)
UC – 10	10 (0.39inch)	400 x 100 x100	428 (62ksi)	50 (7.2ksi)
UC – 10	10 (0.39inch)	500X100X100	428 (62ksi)	50 (7.2ksi)
C – 10	10 (0.39inch)	500X100X100	428 (62ksi)	50 (7.2ksi)
C – 10	10 (0.39inch)	500X100X100	428 (62ksi)	45 (6.5ksi)
C – 10	10 (0.39inch)	500X100X100	428 (62ksi)	45 (6.5ksi)
UC- 12	12 (0.47inch)	480X100X100	436 (63ksi)	45 (6.5ksi)
UC- 12	12 (0.47inch)	480X100X100	436 (63ksi)	45 (6.5ksi)
UC- 12	12 (0.47inch)	600X100X100	436 (63ksi)	43 (6.2ksi)
C – 12	12 (0.47inch)	600X100X100	436 (63ksi)	43(6.2ksi)
C – 12	12 (0.47inch)	600X100X100	436 (63ksi)	43 (6.2psi)
C – 12	12 (0.47inch)	600X100X100	436 (63ksi)	43 (6.2psi)

Table 4 Measured strain and load values for 12 mm (.47inch) bar

Specimen length(mm)	Type of rod	Parameter					
600	UNCOATED	Applied Load(kN)	0	11.3	22.6	33.9	-
		Avg Strain(X10^-4)	0	3	3.5	9	-
		TS Strain(X10^-4)	0	9	17.5	23	-
		Avg Force In Concrete(kN)	0	4.58	14.8	13.7	-
		Avg Force In Steel(kN)	0	6.72	7.8	20.2	-
600	COATED	Applied Load(kN)	0	11.3	22.6	33.9	-
		Avg Strain(X10^-4)	0	0	2	20	-
		TS Strain(X10^-4)	0	12	19	12	-
		Avg Force In Concrete(kN)	0	0	18.2	10.9	-
		Avg Force In Steel(kN)	0	0	4.4	44.8	-
480	UNCOATED	Applied Load(kN)	0	11.3	22.6	33.9	45.2
		Avg Strain(X10^-4)	0	0	0	2	6
		TS Strain(X10^-4)	0	12	21	30	56
		Avg Force In Concrete(kN)	0	11.3	22.6	29.5	31.8
		Avg Force In Steel(kN)	0	0	0	4.4	13.4
480	COATED	Applied Load(kN)	0	11.3	22.6	33.9	45.2
		Avg Strain(X10^-4)	0	0	0	1	4
		TS Strain(X10^-4)	0	12	21	31	38
		Avg Force In Concrete(kN)	0	11.3	22.6	31.7	36.3
		Avg Force In Steel(kN)	0	0	0	2.2	8.9

* UC-Uncoated bar, C-coated bar followed by diameter of bar

Table 5 Measured strain and load values for 10 mm (0.39inch) bar

Specimen length(mm)	Type of rod	PARAMETER					
500	UNCOATED	Applied Load(kN)	0	7.8	15.7	23.5	31.4
		Avg Strain(X10^-4)	0	0	0	0	2
		TS Strain(X10^-4)	0	8	18	28	42
		Avg Force In Concrete(kN)	0	7.8	15.7	23.5	28.26
		Avg Force In Steel(kN)	0	0	0	0	3.14
500	COATED	Applied Load(kN)	0	7.8	15.7	23.5	31.4
		Avg Strain(X10^-4)	0	0	0	2	6
		TS Strain(X10^-4)	0	8	18	26	38
		Avg Force In Concrete(kN)	0	7.8	15.7	20.4	21.98
		Avg Force In Steel(kN)	0	0	0	3.14	9.42
400	UNCOATED	Applied Load(kN)	0	7.8	15.7	23.5	31.4
		Avg Strain(X10^-4)	0	0	0	0	1
		TS Strain(X10^-4)	0	8	18	28	43
		Avg Force In Concrete(kN)	0	7.8	15.7	23.5	29.8
		Avg Force In Steel(kN)	0	0	0	0	1.6
400	COATED	Applied Load(kN)	0	7.8	15.7	23.5	31.4
		Avg Strain(X10^-4)	0	0	0	0	3
		TS Strain(X10^-4)	0	8	18	28	39
		Avg Force In Concrete(kN)	0	7.8	15..7	23.5	26.7
		Avg Force In Steel(kN)	0	0	0	0	4.7

Table 6 Load at first crack and crack spacing in specimen

DIAMETER ϕ mm	SPECIMEN LENGTH	COATED(C) / UNCOATED(UC)	AVERAGE CRACK SPACING (CM)	LOAD AT FIRST CRACK (KN)
12 (0.47inch)	600 (23.22inch)	UC	14.92 (5.87inch)	30 KN (6.7kilopounds)
12 (0.47inch)	600 (23.22inch)	C	16.43 (6.48inch)	30 KN (6.7kilopounds)
12 (0.47inch)	480 (18.89inch)	UC	17.64 (6.9inch)	30 KN (6.7kilopounds)
12 (0.47inch)	480 (18.89inch)	C	20.87 (8.21inch)	30 KN (6.7kilopounds)
10 (0.39inch)	500 (19.68inch)	UC	16.98 (6.7inch)	35 KN (7.8kilopounds)
10 (0.39inch)	500 (19.68inch)	C	18.17 (7.15inch)	40 KN (8.9kilopounds)
10 (0.39inch)	400 (15.71inch)	UC	15.4 (6.06inch)	52.4KN (11kilopounds)
10 (0.39inch)	400 (15.71inch)	C	**	51 KN (11kilopounds)

**Testing error.

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