Tensile response of reinforced ties cast with self-compacting concrete

Atef DAOUD
Dr.Ing.
ISA-BTP
Anglet, France

Michel LORRAIN
Professor
INSA
Toulouse, France

Summary

Investigations on cracking behaviour of self-compacting concrete (SCC) have been carried out by means of tension ties tests. The test program was prepared to study the influence of intrinsic parameter of the connection concrete-steel (bar diameter: reinforcement ratio and bar roughness) on cracking of SCC, allowing a comparison with the known performances of vibrated concrete (VC). We found that crack spacing depend mainly on the reinforcement ratio and the bar roughness but no significant changes due to the use of SCC is observed. The use of SCC has no incidence on the average crack width.

Keywords: self-compacting concrete, vibrated concrete, bond, reinforced concrete ties, crack spacing and width

1. Introduction

Self-compacting concrete is proportioned to be highly flowable to spread into place under its own weight and achieve good consolidation without internal vibration. Indeed, beside usual components, self-compacting concrete use water reducer, viscosity admixture and high quantity of powder. The water reducer is used to ensure high fluidity and to reduce the water-cement ratio [1].
The viscosity admixture is incorporated to enhance the yield value and viscosity of the fluid mixture, hence reducing bleeding and segregation [2]. To have a good deformability and high filling capacity, the coarse aggregate content is reduced [3] and a higher volume of fine is used (generally another addition than cement like fly ash, limestone powder…).
Bond between steel and concrete is influenced by many factors, related to the hardened concrete properties, reinforced steel properties, loading regime …It depends, also, on the fresh concrete properties and particularly the mix design.
Some studies have been devoted to the bond between steel and self-compacting concrete and the most results can be summarised as follows:

- The influence of bar position is less distinct in SCC than in VC [1][4]
- Contradictory results are observed concerning bond strength related to concrete compressive strength of SCC [5][6]
- SCC seems to be more sensitive to bar roughness than VC [7]

Strength, deformability and durability of reinforced concrete structure depend on concrete cracking behaviour, concrete and steel deformability, cracking distribution in the structure and bond between concrete and steel.
From this statements and following former work related to bond between steel and self-compacting concrete, we implemented a research program directed toward the study of the influence of intrinsic parameter (bar diameter, bar roughness) on the cracking behaviour of SCC, allowing a comparison with the known performances of vibrated concrete, ordinary and high performances.

2. Experimental method

2.1 Test implementation

The reinforced concrete ties are subjected to an axially imposed load (fig. 1). The tension imposed load increased monotonically up to steel yield level when the concrete tie was tested with aid of an 250kN hydraulic jack.
The total elongation was measured by an LVDT placed between the two edge of the specimen. The local elongation and crack width were measured with nine L.V.D.T placed on the side of the specimen (fig. 2).

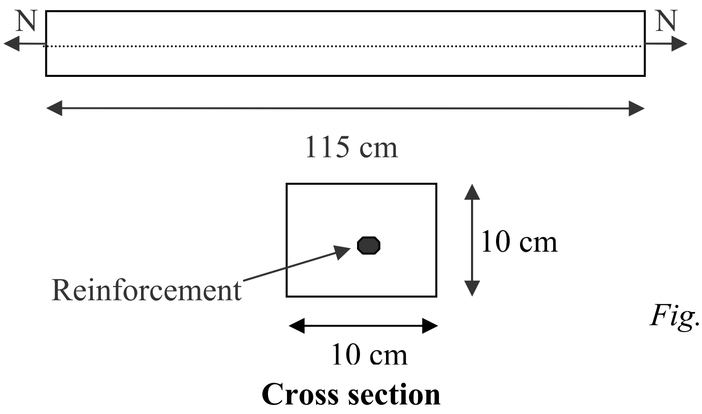

Fig.1 Specimen details

Fig.2 Position of the L.V.D.T (local elongation)

2.2 Experimented concrete

The mixtures proportions selected for this study are given in tables 1. We are looking for 45 MPa strength at 28 days in simple compression.

	PROPORTIONING (kg/m^3)	
COMPONENT	SCC	VC
Cement CPA CEM 52,5 R	330	350
Marble powders	143	-
Sand 0/5	900	668
Broken up particles 5/12	856	1293
Viscocrete 2100	3.25	-
Viscocrete 3010 SCC	5.2	-
Water	188	200

Tab. 1 Mixture proportion of concretes

Three tests were carried out on the SCC used in a fresh state: the slump flow test (fig.3), the L-box test (fig.4) and segregation test (in accordance with AFGC recommendations [8]. For VC, only slump test was applied. The test results are summed up in table 2.

	SCC	AFCG Recommendations	VC
Slump flow (mm)	[650-680]	600<slump flow<750	-
Filling capacity (%)	[85-90]	>80	-
Milt (%)	6.5-10	0<% milt<15	-
Slump (mm)	-	-	60

Tab.2 Characteristics of concretes in the fresh state

No external bleeding was observed on top surface of any SCC specimen. These values indicate an excellent deformability without blockage among closely spaced obstacles.

For each concrete batch compressive and splitting tensile tests were performed on 12*24 cm cylindrical samples at 14 days age. The characteristics are summed up in table 3.

	SCC	VC
f_c (MPa)	42-45	45
f_t (MPa)	2.5-3.1	3.4

Tab.3 Mechanical performances of the hardened concretes

Fig.3: L-box test

Fig.4: Slump flow test

2.3 Reinforcements

Two types of bars were used: deformed bar type FeE500 presenting the usual profile of two fields of different bolts separated by two longitudinal veins and smooth bar type FeE235.

3. Experimental results

3.1 Steel stress-strain relationship

Results are presented as relationship between steel stress and strain of the reinforced concrete tie. Figure 5 gives a typical example of steel stress-strain curve for a reinforced SCC tie and a reinforced VC one.
We observe that the use of SCC does not change the behaviour of RC tie, under imposed load, at all the stage of the evolution: uncracked phase, crack formation and stabilized cracking.

3.2 Crack spacing

The cracks development is described in figure 6. We observe two kinds of cracks network:
For deformed bar: under increasing load, one can first observe the primary cross crack normal to the tie axis. Then, under higher load, axial cracks due to the concrete splitting failure take place from the primary crack. At last, a secondary transverse network of cracks grows from the splitting crack
For smooth bar: under increasing load, one can first observe the primary cross crack normal to the tie axis. Even under higher load, we can't observe other cracks
This result is related to a different bond mechanism for smooth and deformed bar.
For the measure of the experimental mean crack spacing, we only considered the primary cross crack, due to the steel to concrete bond [9]. Figure 7-a describes the variations of the average crack spacing measured in the stabilized cracking phase with the bar diameter-steel percentage ratio, for SCC and VC. This ratio is proved to be the most influential parameter on the crack spacing behaviour [10][11]. The observed variations show that average crack spacing does not vary significantly between SCC and VC. This can be explained by the constancy of the concrete tensile strength-average bond stress ratio [12], observed in a former work [7].
Figure 7-b presents the variations of the average crack spacing measured in the stabilized cracking phase with the bar diameter-steel percentage ratio, for deformed and smooth bar.

We observed that the average crack spacing is higher for smooth bar then deformed bar. This result is similar to the known one concerning the VC since [9] and what predict eurocode2 and CEB FIP Code Model. Moreover, relationships from crack theories expressing the average crack spacing for VC structural element, proportional to the bar diameter-effective reinforcement ratio proportion still apply to SCC structures.

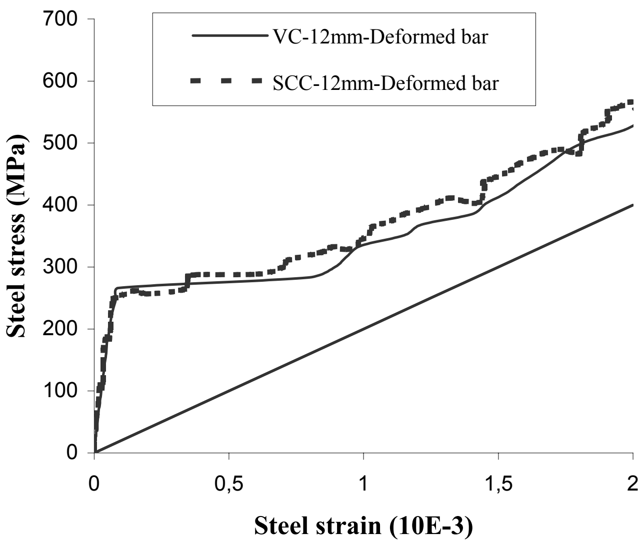

Fig.5: Steel stress-strain relationship of a RC tie

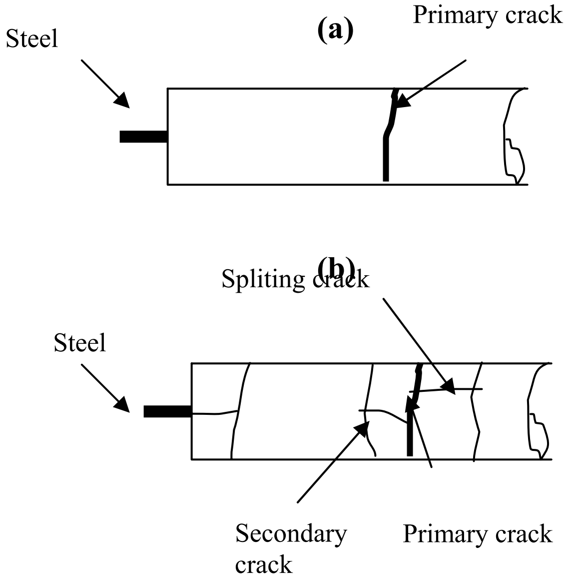

Fig.6: Crack development (a)for smooth bar (b) for deformed bar

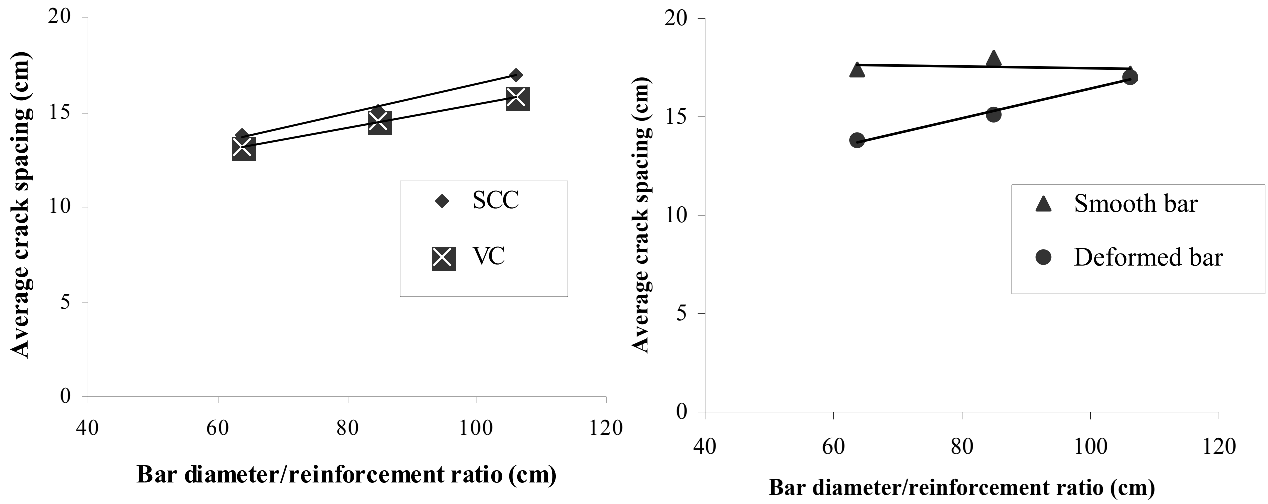

Fig.7: Influence of bar diameter-reinforcement percentage ratio on the average crack spacing (a) for SCC and VC: deformed bar (b) for deformed and smooth bar: SCC

3.3 Average crack width

The average crack width is obtained from the following relation:

$$w_m = \sum_{i=1}^{n} \frac{w_i}{n} \qquad (1)$$

with n: number of cracks at a given steel stress level
w_i : crack width locally measured
w_m : average crack width

Figure 8 shows the effect of bar diameter (reinforcement ratio) and concrete nature (SCC and VC) on the evolution of the average crack width with the steel stress.
We observed a considerable scattering during the crack formation phase, and a linear curve during the stabilized phase.
We can deduce from that the higher the bar diameter, the lower the average crack width, for both SCC and VC.
No significant difference, between the average crack width of reinforced SCC and VC ties, can be observed. Indeed, a difference of only 6% is noted between SCC and VC.
[13] have found that SCC presents an average crack width lower than VC. They have noted a difference of 25%. We must say that the SCC, used by the authors, have a compressive strength higher than VC (23%).
We describe in figure 9 the effect of bar roughness on the variations of the average crack width, for SCC. We observed an average crack width higher for smooth bar than deformed bar. A difference of 15% is noted.
This result is similar to those known since[14].
The observed result show that the effect of bar roughness isn't as significant as the one noted in anchorage behaviour [7]. We think that for the maximum crack width of RC (smooth bar) tie is 0,25mm (corresponding to a bar slip of 0,125mm), at this slip bond strength is ensured only by cohesion and friction for smooth and deformed bar; the rib bearing doesn't act yet for deformed bar.

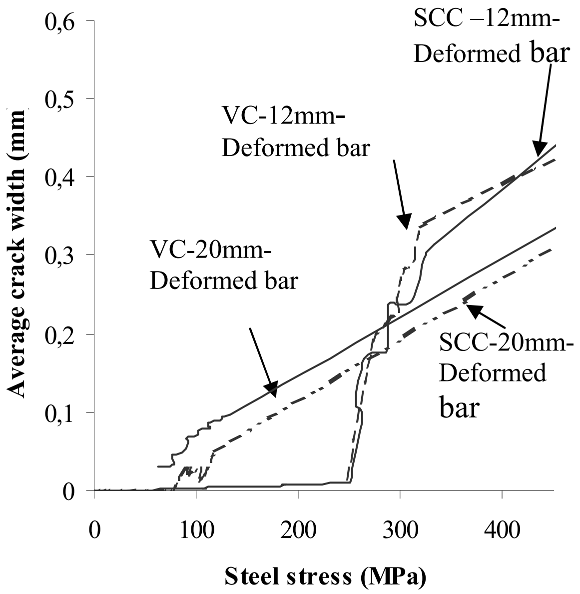

Fig.8:Influence of bar diameter on the average crack width for SCC and VC

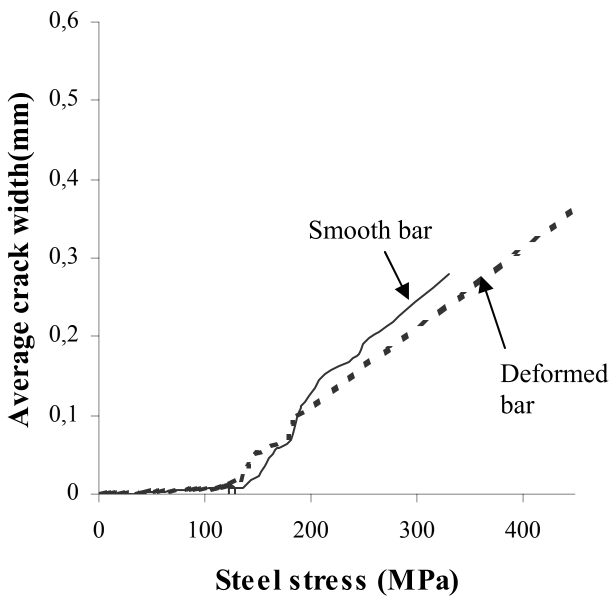

Fig.9: Influence of bar roughness on the average crack width for SCC

4. Conclusions

Cracking behaviour of SCC have been studied by means of tension ties tests. Based on the results in this paper, we can draw the following conclusions:

1- The cracking behaviour of tension ties cast with SCC exhibited similar behaviour than those cast with VC in terms of cracks network and stress-strain relationship.
2- No significant differences were observed between SCC and VC in terms of crack width and spacing.
3- The influence of bar roughness is not as significant as observed in anchorage behaviour of SCC

References

[1] AITCIN P.C., SARKAR S.L., LAPLANTE P., « Long term characteristics of a very high strength concrete», *Concrete international: Design and construction*, vol.12, n°1,1990, p40-44

[2] KHAYAT K.H. ; MANAI K. ; TRUDEL A. « In situ mechanical properties of wall elements cast using self-compacting concrete », *ACI*, vol 94, n°6, nov-dec 1997, p491-500

[3] YURIGI M. ; SAKATA N. ; IWAI M. ; SAKAI G. , « Mix design for highly workable concrete », *Conference concrete 2000*; Dundee, 7-9 septembre 1993,11p

[4] KHAYAT, K.H. " Use of viscosity-Modifying Admixture to reduce top-bar effect of anchored bars cast with fluid concrete", *ACI Materials Journal,* V.95, N°2,1998, pp.158-167

[5] SONEBI, M., BARTOS, P.M.J. " Hardened SCC and its bond with reinforcement", *Proceedings of RILEM International Symposium on SCC*, Stockholm 1999, pp. 275-290

[6] KONIG, G., HOLSCHEMACHER, K., DEHN, F., WEISSE, D. "Self-compacting concrete-time development of material properties and bond behaviour", *Proceedings of the second International Symposium on SCC*, Tokyo 2001, pp.507-516

[7] DAOUD, A., LORRAIN, M., ELGONNOUNI, M. " Résistance à l'arrachement d'armatures ancrées dans du béton auto-plaçant", *Materials and structures,* V.35, N° 251, 2002

[8] AFGC-Groupe de travail « Bétons autoplaçants » " Les bétons autoplaçants- Recommandations provisoires ", *Annales du bâtiment et des travaux publics* ; N°3 ; 2000

[9] GOTO Y. , « Cracks formed in concrete around deformed tension bars», *ACI Journal*, n°4, proceedings V.68, 1971, p.244-251

[10] CEB-FIP Model Code , *Bulletin d'information du CEB n°203-204-205*, 1991,Final Draft

[11] EUROCODE 2 , « Calcul des structures en béton, Partie1: règles générales et règles pour les bâtiments », projet de norme européenne, 1992

[12] LORRAIN M., MAUREL O., SEFFO M. , « Cracking behaviour of reinforced high-strength concrete tension ties», *ACI Structural Journal*, sep-oct, vol.95, 1998, p.626-635

[13] SONEBI M., BARTOS P.J.M., TAMIMI A.K. , « Flexural response and performance of reinforced beams cast with self-compacting concrete», *Proceedings of the second symposium on self-compacting concrete*, oct., Tokyo 2001, p.517-526

[14] BASE G. , « Bond and control of cracking in reinforced concrete», *Proceedings of "Bond in concrete"* édité par P.BARTOS (applied science publishers), 1982