Corrosion-induced cracking and bond behaviour of corroding reinforcement bars in SFRC


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ABSTRACT
In this study, an experimental programme has been carried out to investigate the influence of fibres on the onset of corrosion-induced splitting cracks. Cylindrical lollipop specimens with a centrally positioned Ø16 mm bar and varying cover depths from 40 to 64 mm were subjected to accelerated corrosion. A constant current of 100 $\mu A/cm^2$ was impressed through the specimens and the electrical resistance between each rebar and an external copper mesh acting as cathode was monitored. The fibres, due to their confining effect, contributed to delay crack initiation, improve the post-peak bond behaviour and retain the initial splitting strength for corrosion levels of up to 8%.

Key words: Chlorides, Corrosion, Cracking, Fibres, Reinforcement.

1. INTRODUCTION

The present study aimed at investigating two distinct phenomena which have been seldom addressed in the past, namely: (1) the influence of steel fibres at low dosages on the onset of splitting cracks induced by corroding conventional reinforcement; and (2) the bond behaviour of corroded reinforcement bars embedded in steel fibre reinforced concrete (SFRC). These aspects were addressed experimentally and the results include the corrosion level associated to crack initiation, crack width measurements of corrosion-induced cracks, the evolution of the bond strength with increasing corrosion and a comparison of the anchorage capacity based on the local bond-slip relationship obtained. For a more detailed description of the results see [1].

2. EXPERIMENTAL PROGRAMME

The experimental programme involved 42 specimens and to assess the influence of fibres on the bond capacity of corroded reinforcement bars pull-out tests were performed at three different corrosion stages. Accordingly, the specimens were divided into three groups: group I, uncorroded specimens used as reference samples; group II, specimens corroded up to the onset of corrosion-induced cracking; and group III, specimens corroded beyond the onset of splitting cracks. Furthermore, two different cover to bar diameter (Ø 16 mm) ratios, *c/Ø*, were investigated for the bond-behaviour and a third one was included for the crack initiation stage. Table 1 summarizes the details of the experimental programme.

Table 1. Experimental programme.

	Corrosion stages and concrete type					
	Group I Uncorroded - Reference		Group II Crack onset		Group III High corrosion	
c/Ø ratio	PC	FRC	PC	FRC	PC	FRC
2.5	x	x	x	x	x	x
3.25	-	-	x	x	-	-
4.0	x	x	x	x	x	x

Note: Three specimens were cast for each combination of *c/Ø* ratio and corrosion stage investigated.

A self-compacting concrete mix with a water to cement ratio (*w/c*) of 0.47 was prepared to cast all the specimens using individual moulds. The same mix composition was used to prepare both the plain and the steel fibre reinforced concrete, except for minor variations in the aggregate content to incorporate the fibres. End-hooked Dramix steel fibres, 35 mm long with diameter 0.55 mm, were used as fibre reinforcement at a dosage of 40 kg/m^3. Sodium chloride was incorporated into the mix at 4% by weight of cement with the intention of preventing the formation of the passive layer on the steel bar. The accelerated corrosion and the pull-out setup is presented in Figure 1.

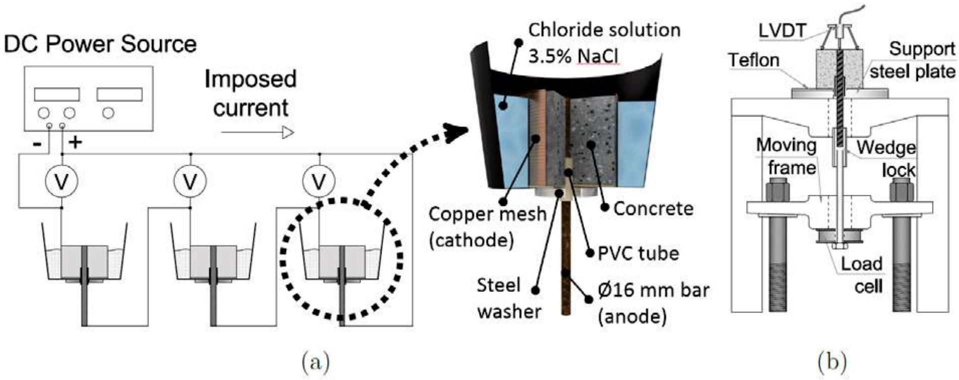

Figure 1. Accelerated corrosion setup (a) and the pull-out test (b) (bonded length 70 mm).

3. RESULTS AND DISCUSSION

The relation between corrosion level, defined as the steel loss assumed to be concentrated and uniformly distributed along bonded length of the bar, and crack initiation is presented in Fig. 2. The results clearly shows that, from the parameters investigated in this study, the *c*/*Ø* played the most important role in delaying the initiation of corrosion-induced cracks, although its effect was more pronounced in PC specimens. Increasing the *c*/*Ø* from 2.5 to 4.0, delayed crack initiation by a factor of 2 and 1.5 for PC and FRC specimens in Group II, respectively, whereas it delayed crack initiation by a factor of 4 and 1.75 for PC and FRC specimens in Group III, respectively. Adding fibre reinforcement had likewise a positive effect in delaying crack initiation, although to a lesser degree compared to the *c*/*Ø*, which was particularly noticeable in small *c*/*Ø* test specimens.

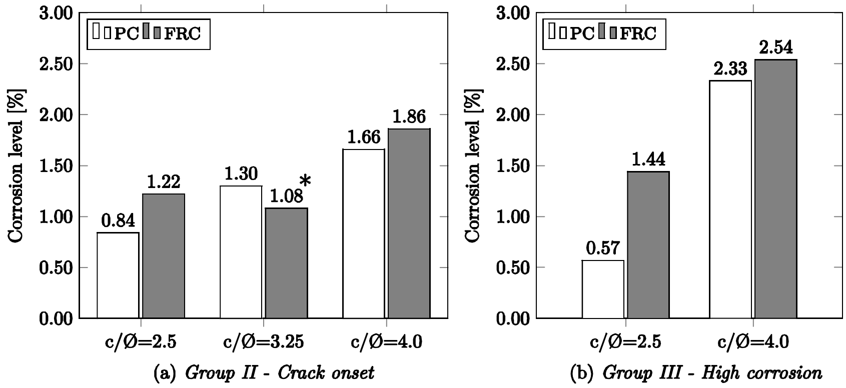

*Figure 2. Average corrosion levels at crack initiation. *FRC specimens with c/Ø=3.25 in Group II deviated from the general trend followed by the rest of specimens and were considered outliers.*

In order to compare the pull-out test results of the PC and FRC specimens for the different covers and corrosion stages in detail, the splitting strength from each experimental curve is presented in Figure 3(a) as a function of the corrosion level. As expected, for the reference group, there was not a significant difference between PC and FRC in terms of splitting strength since the fibres did not prevent cracking, whereas a small increase, attributable to the cover size, was apparent. Upon corrosion-induced cracking, PC specimens suffered a moderate reduction of the splitting strength whereas it slightly increased for FRC, an effect that may be attributed to a higher normal stress at the interface due to corrosion. Finally, at higher corrosion levels the remaining splitting strength of PC specimens was only a small fraction of the initial, with no apparent influence of the cover depth. Highly corroded FRC specimens, on the other hand, exhibited a nearly identical splitting strength as uncorroded ones.

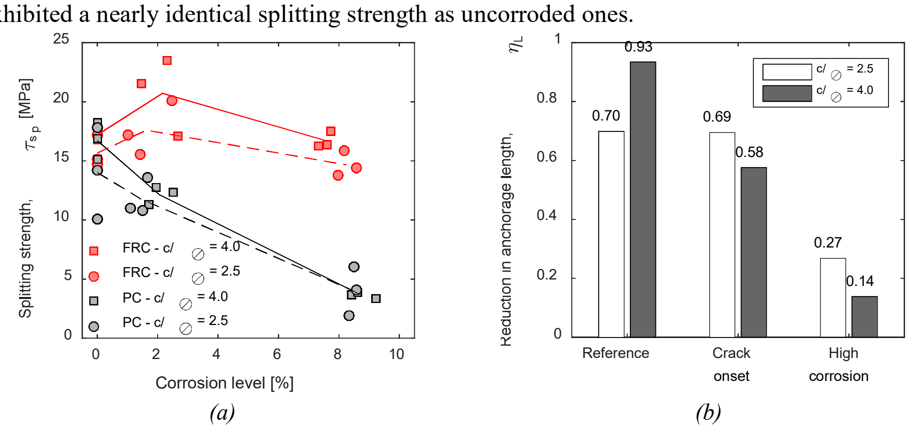

Figure 3. (a) Splitting strength determined experimentally as a function of the corrosion level at structural testing for PC and FRC (lines show the average behaviour). (b) Reduction in the needed bar length to anchor the yield strength of a Ø16 mm rebar with yield stress 550 MPa in FRC compared to PC, obtained using 1D numerical analysis and the experimental bond-slip as input.

Figure 3(b) shows the reduction of anchorage length in FRC compared to PC to fully anchor the yield strength of the rebar, expressed as the fraction of length needed. The addition of fibres resulted in an anchorage length reduction of 30% at an uncorroded stage, whereas that effect was not as evident for large specimens due to the higher confinement provided by the concrete cover. These results show that as the cover increases and approaches “well confined” conditions ($c/Ø$ = 5 according to Model Code 2010 [2]), the beneficial effect of the fibres on the anchorage length decreases, which is in line with results reporting that low fibre contents will not significantly influence the behaviour of RC elements exhibiting pull-out failure.

4. CONCLUSIONS

This paper briefly reports experimental results regarding the corrosion level associated to the initiation of splitting cracks in PC and FRC, as well as results of pull-out tests with short-embedment length carried out for both PC and FRC at various corrosion stages. Based on the results of the study, the following conclusion may be drawn:

(1) The use of steel fibres at a 0.5% vol. dosage provided an additional source of passive confinement that delayed corrosion-induced cracking. This effect was more noticeable in specimens with a smaller c/Ø, whereas it became less apparent for larger $c/Ø$ in which the cover already provided a significant confinement to the rebar.

(2) As expected, for uncorroded specimens, the results from the pull-out tests showed no significant difference between PC and FRC specimens regarding the splitting strength. For increasing corrosion levels, however, the splitting strength of PC specimens exhibited a clear degradation, particularly for specimens with a larger cover. Conversely, FRC specimens retained their initial splitting strength at 8% corrosion and even showed a slight increase at intermediate corrosion levels.

(3) The pull-out tests revealed a clear contribution of the fibres on the post-peak capacity regardless of the size and corrosion level. Based on the 1D analyses, the anchorage length in FRC specimens subjected to 8% corrosion was only increased by 10% compared to uncorroded reference specimens, unlike for PC specimens in which the anchorage length at the same corrosion level increased by a factor ranging from three to seven.

In addition to what has been presented in this paper, crack width measurements revealed that cracks in FRC were around half as wide at corrosion levels approaching 8%. Moreover, fibre reinforcement proved to be an effective means of preventing spalling of the concrete cover, understood as both its physical detachment and the loss of its mechanical contribution to the structure.

REFERENCES

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