

Experimental Investigation on Rebar Corrosion in Combination with Fibres



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ABSTRACT

In this paper, early results from an on-going project aimed at investigating the influence of fibre reinforcement on corrosion of rebar are presented. Resistivity of mixes containing fibres was reduced when compared with plain concrete while chloride migration seemed to remain unaffected. On the mechanical properties, results showed that while the flexural behaviour was greatly enhanced by addition of fibres up to 0.5% vol., the variation in compressive strength was negligible regardless of the fibre type. Early results from the main experiments indicated a tendency of earlier corrosion initiation with increasing crack width, and that the initiation time was somewhat delayed for the fibre reinforced specimens.

1. INTRODUCTION

Civil engineering structures like bridges and harbour piers require the use of a dense concrete (low w/c ratio), thick concrete covers and strict crack width limitations due to the risk for chlorides to cause reinforcement corrosion. In practice, this leads to large reinforcement amounts which often cause complications in production, but still with difficulties in controlling the surface crack width due to the large concrete cover. Fibre reinforcement has been extensively used in applications such as buildings, floors or slabs on grade for crack control (Bentur and Mindess 2007). Therefore, it would be beneficial to use fibres, in complement to the traditional reinforcement, also in civil engineering structures where their crack limiting effects are of interest.

However, the use of fibres in combination with conventional reinforcement in chloride environments raises questions due to the limited research available in this field. Some of these questions are related to the influence fibres may have with respect to chloride ingress and moisture transport. The main issues that have yet to be dealt with are the potential risk of galvanic corrosion due to the different steel types used in the fibres and in the traditional reinforcement, and the risk of higher corrosion rates due to lower resistivity of steel-fibre reinforced concrete. In an on-going Ph.D. project at Chalmers University of Technology, the

authors investigate the durability of concrete structures with regard to chloride induce corrosion when fibre reinforcement is combined with conventional reinforcement.

2. EXPERIMENTAL PROGRAMME

The main task in the project consists of a long-term experimental campaign specifically conceived to answer the aforementioned questions. The experiments include a total of 56 beam specimens with dimensions 100×180×1100 mm and reinforced with 3 Ø10 mm diameter rebar as illustrated in Figure 1. The reinforcement was placed to get a clear concrete cover of 30 mm and the separation between bars was kept to 45 mm to allow the fibres to easily flow through them and ensure a more homogenous material.

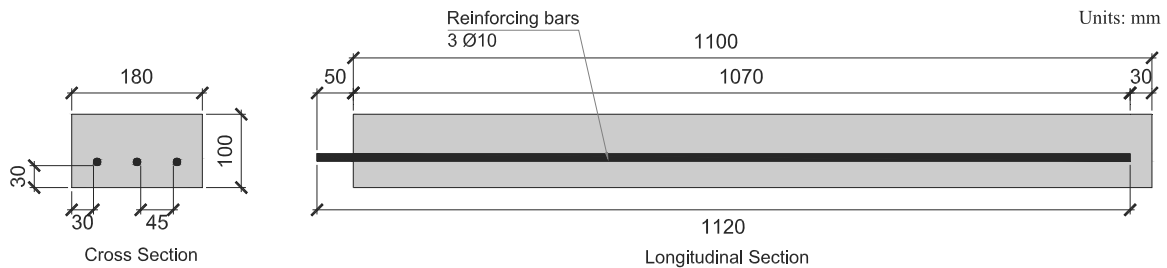


Figure 1. Geometry of the test specimens

A single concrete mix and three types of fibres were used to cast four different types of concrete, hereafter referred as to: *plain*, for ordinary concrete; *steel*, for steel-fibre reinforced concrete; *hybrid*, for a combination of steel and micro polyvinyl-alcohol fibre reinforced concrete; and *synthetic*, for macro polyvinyl-alcohol fibre reinforced concrete. Table 1 shows the mixture proportion and fibre dosages used in each mix. Further parameters varied are the loading conditions, including sound specimens (never cracked) and specimens cracked and subjected to cyclic loading (bond degradation), sustained loading, or no loading. Also the influence of surface crack width is studied with openings ranging from 0.1 to 0.4 mm. Six specimens are kept immersed in potable water as a reference while the rest are exposed to an accelerated process of natural corrosion by partial immersion in 10% Cl⁻ solution and cycles of 14-day wetting and 14-day drying. Moreover, companion specimens to study chloride ingress, chloride migration and resistivity of concrete, as well as compressive strength and flexural behaviour of fibre concrete were cast.

Table 1. Mixture proportions, kg/m³

Component				
Cement (CEM I 42,5N SR 3 MH/LA)				360
Limestone filler (Limus 40)				165
Fine aggregate (Sand 0/4)				770
Coarse aggregate (crushed 5/16)				833
Effective water				169
Superplasticizer – Glenium 51/18				5.76
Air entrainer – MicroAir 105				0.72
Fibre (Volume, %)	Plain	Steel	Hybrid	Synthetic
Steel – Dramix [®] 65/35-BN	-	0.5	0.35	-
PVA – Kuralon [™] RFS400	-	-	0.15	-
PVA – Kuralon [™] RF4000	-	-	-	0.75

3. RESULTS AND DISCUSSION

Some results are shown in Figure 2, as can be seen, the addition of fibres in low dosages had a marginal effect on the compressive strength of concrete. Similarly, no significant variation was observed in the chloride migration coefficient for the different mixes. These results are in agreement with those from (Sanchez, Alonso, and Barragán 2009) or (Teruzzi et al. 2004) who concluded that the interfacial zone between fibres and the cement paste does not act as a preferential path for the ingress of detrimental agents. Resistivity tests, on the other hand, revealed a clear influence of fibres on this property. Resistivity of series containing steel fibres is invariably reduced with lower values for higher fibre contents. Moreover, synthetic series, with PVA fibres, also show a decrease in resistivity with respect to their ordinary concrete counterpart. Similar results are reported in (Roque et al. 2009), indicating that PVA fibres, despite their high resistivity ($\sim 3.5 \cdot 10^5 \Omega\text{m}$) and unlike other fibres such as polypropylene, may reduce the resistivity of concrete.

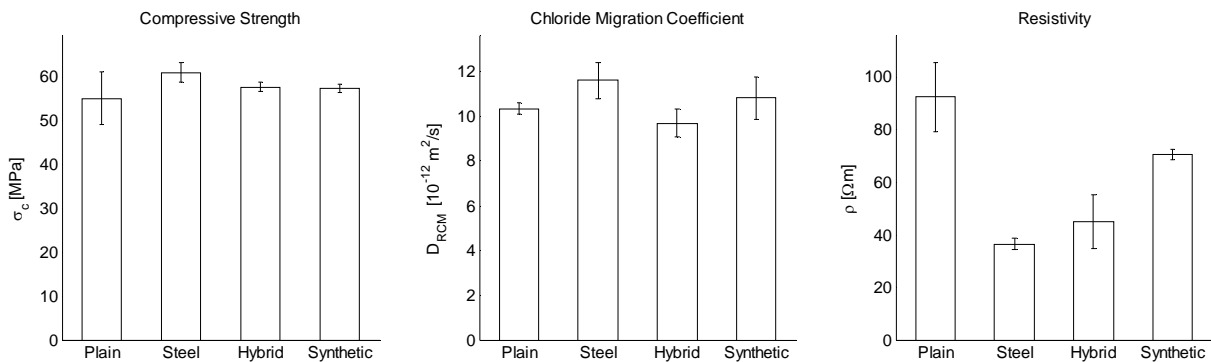


Figure 2. Results on material tests for compressive strength, chloride migration coefficient and resistivity of concrete (mean values and standard deviation for 3 specimens)

The flexural behaviour of fibre reinforced concrete was studied by means of three-point bending tests according to (RILEM TC 162-TDF 2002). Figure 3 evidences the enhanced flexural behaviour of fibres in terms of toughness while the increase in tensile strength is negligible.

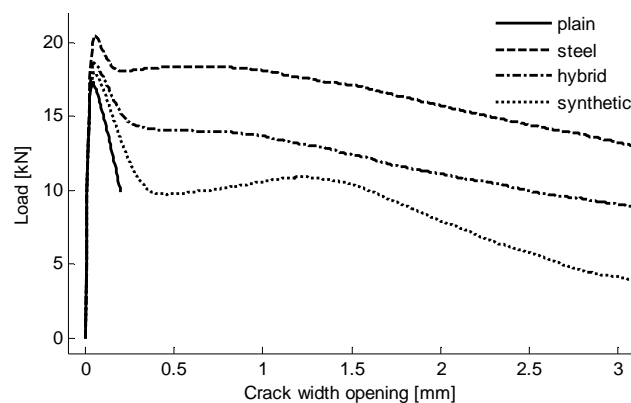


Figure 3. Load versus crack mouth opening displacement for three-point bending beam tests (Averaged curves for 6 specimens each)

In the long-term experiments, half-cell potential (HCP) are continuously monitored using an embeddable reference electrode. HCP describes the thermodynamic state of a metal's surface and, alone, does not provide information about the corrosion rate. However, it can indicate whether the reinforcement is actively corroding or in a passive state and it may suggest a range

of corrosion rates. A proposed range to determine the probability of corrosion can be found in (ASTM C876-91 1999). Based on that, the corrosion initiation times of each mix are shown in Figure 4 for varying crack width and for 3 different loading conditions. Note the difference in scales for loaded and unloaded series; the shorter initiation times for the loaded specimens are due to the cracks being kept open, while the values of the crack width in the other two series was the measured ones *before* unloading. A clear tendency is observed where larger crack widths led to earlier corrosion, except for the loaded specimens, where corrosion generally started soon after the first exposure to chlorides regardless of the crack opening. Additionally, a slight delay in the corrosion initiation time is observed for the fibre-reinforced mixes.

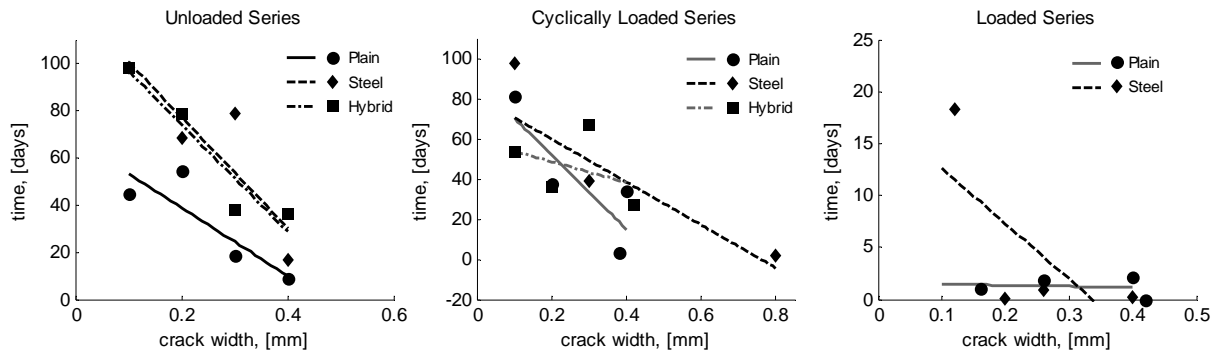


Figure 4. Corrosion initiation times for different loading conditions

4. CONCLUSIONS

The results from this investigation indicate that controlling the crack width is crucial in order to delay the initiation of corrosion in reinforced concrete structures. Fibre reinforcement can effectively control the crack width and provides a considerable improvement of the tensile properties of concrete in terms of toughness. Besides, given the same surface crack width, results show that corrosion initiation was somewhat delayed for fibre-reinforced mixes. On the physical properties, no adverse effect is detected regarding the chloride migration coefficient for FRC. Conversely, electrical resistivity is greatly decreased by the presence of steel fibres, and even in the case of PVA fibres, results show a reduction. Today, this fact represents the major impediment to use fibre reinforcement in combination with conventional rebar in chloride environments, as there are concerns that a reduced resistivity will increase the corrosion rates. Therefore, further investigations are required to address this issue.

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