EFFECT OF REINFORCEMENT CORROSION ON THE PUNCHING SHEAR OF RC SLABS INCORPORATING MACRO SYNTHETIC FIBERS

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This paper is part of an ongoing research on the effect of discrete fiber reinforcement on punching shear strength of reinforced concrete (RC) slabs subjected to accelerated corrosion regime of steel reinforcement. Results obtained from RC slabs incorporating macro synthetic fibers will be presented. Six RC slabs (1500 mm ×1500 mm ×100 mm) were prepared with a constant reinforcing steel ratio and incorporating synthetic fibers at different dosages (0.0%, 0.5% and 0.75% by volume). The corroded set of slabs were subjected to an impressed current (IC) accelerated corrosion regime for 36 days with an applied constant current density of 500 µA/cm². The slabs were subjected to wetting-drying cycles of 1 day wet and 2 days dry. During the wet cycle, the slabs were fully submerged in a 3.5% NaCl solution. The applied current results in a theoretical mass loss of steel by around 7%. The slabs were tested in a simply supported configuration until failure. The measured test parameters included the applied load, the slab deflection, and the observed cracking. The results showed that reinforcement corrosion affected the slabs' performance in terms of strength and deflection capacities, as well as the cracking behavior. The load-deflection response showed that the addition of synthetic fibers could reduce the impact of steel corrosion on the punching shear behavior of the RC slab. Furthermore, the presence of synthetic fibers significantly helped in limiting the development of corrosion activity in the slabs by delaying corrosion-induced cracks when compared to the control slabs.

Keywords: Wet-dry cycling, Accelerated corrosion, Constant current, Loading, Deflection.

1 INTRODUCTION

On many occasions, punching shear failure demonstrated its severity in the construction industry. The fact that punching shear failure has a brittle nature makes it extremely catastrophic and horrifying to all structural engineers and designers. Corrosion of steel reinforcement in reinforced concrete (RC) flat slabs has proven to weaken the system (Ikehata et al. 2020, Daneshvar et al. 2021, Qian et al. 2022), thus, leading to punching shear failure in many incidents. Corrosion is detrimental to the mechanical properties of steel. Once the steel is corroded, it slowly becomes useless, therefore, leading to the failure of structures that depend primarily on a steel component that resists stresses and transfers them in some way or another. Many incidents of the collapse of structures due to corrosion have been investigated in the past (Woodward and Williams 1988, Lichtenstein 1993, NTSB 2008). This brings up the significance of methods of reinforcing and strengthening slabs against punching shear failure. Amongst the well-established methods is the
use of discrete fiber reinforcement, which has proven its superior advantages such as limiting the cracks propagation, increasing the toughness, and increasing the load carrying capacity of various structural elements (Harajli et al. 1995, Cheng and Parra-Montesinos 2010, Nguyen-Minh et al. 2011, Alani and Beckett 2013, Grimaldi et al. 2013, Caratelli et al. 2016, Altoubat et al. 2021).

Few researchers have carried out investigations on the impact of corrosion on the punching shear strength of conventionally reinforced slabs, and many others have studied the influence of fiber reinforcement on the mechanical properties of RC slabs. In this study, however, we evaluate the effect of reinforcement corrosion on the punching behavior of RC flat slabs incorporating steel and synthetic fibers, as well as the influence of the fibers and the advantages of adding them in a corroded slab specimen. The addition of fibers is not only expected to compensate for the loss of strength due to corrosion, but also limit to some extent the imposed damage on the specimens due to the development of corrosion products.

2 EXPERIMENTAL PROGRAM

In this study, the punching shear behavior was evaluated for six RC flat slabs reinforced with macro synthetic (MS) polypropylene fibers. Half of the specimens were subjected to accelerated corrosion while the other half was not (reference slabs). The testing matrix of this study is presented in Figure 1. Two MS fiber dosages were used (0.5 and 0.75%), in addition to the reference zero-fiber specimens.

![Testing Matrix](image)

**Figure 1. Testing matrix.**

2.1 Materials

A normal-strength concrete with a target compressive strength of 35 MPa was used for all test slab specimens. The concrete was provided by a local ready-mix concrete plant, after which the fibers were added on site, and specimens were cast, after properly remixing the concrete. All slabs had the same longitudinal reinforcement ratio of 0.9%, which was a single uniform mesh of T12@145 mm c/c both ways. The steel reinforcement used in the slabs was tested in tension to obtain the stress-strain characteristics. With a yielding stress at 570 MPa and ultimate stress at 650 MPa, the specimens showed high ductility demonstrated in an approximately 9% elongation prior to failure. The MS fibers of the type “STRUX BT50” were added to the concrete with two different dosages as mentioned earlier.
2.2 Accelerated Corrosion

The three slabs of set 2 of the testing matrices (the corroded slabs) were subjected to accelerated corrosion regime. In every corroded slab, four rebars were directly connected at their ends to the positive direct current (DC) power supply. An illustrative sketch of the setup is shown in Figure 2. The DC power supply was connected to four (not all) steel rebars which acted as the anode and a separate steel mesh of T12@100 with 700 mm rebar length, which acted as the cathode in this process was connected to the negative outlet of the DC power supply. The steel rebars (the anode) were tied strongly to ensure the current flow through all steel rebars. A constant impressed current accelerated corrosion regime was implemented in this study, and a current density of 500 $\mu$A/cm$^2$ was applied. The three slabs were fully submerged in a NaCl solution tanks (3.5% w/w) and were subjected to wet-dry cycling (1W/2D, i.e., 1 day wet, 2 days dry) to accelerate the corrosion reaction, as recommended in a study by Lee et al. (2000).

At the test day, all slabs were tested for punching shear until failure in a simply supported configuration, where a vertically oriented hydraulic actuator, supported by a steel frame, was used for the load application. During the test, LVDT and strain gauges data were recorded simultaneously.

![Illustrative sketch of the accelerated corrosion setup](image)

Figure 2. Illustrative sketch of the accelerated corrosion setup.

3 RESULTS AND DISCUSSION

3.1 Influence of Fibers on Corrosion Development

In the corrosion setup, the current was fixed through the anode-cathode cell, and the corresponding cell potential was measured to monitor the corrosion development and rate of corrosion. The cell potential was recorded from the DC power supply every beginning and end of a wet cycle. Figure 3 presents a comparison between the corroded control slab (without fibers) with the other two slabs in terms of the development of cell potential throughout the 36 days of accelerated corrosion. The continuous ups and downs of the line graphs are due to the wet-dry cycling. When the solution was removed from the tanks during the dry cycle, the electrical circuit was cut and the DC power supply...
supply unit was switched off, which resulted in reduction in the cell potential. In other words, during the wet cycle, the potential increases due to the corrosion development and cracks, then, when the dry cycle comes, the potential decreases. It is clearly obvious that in all specimens, the cell potential started at a relatively low value of voltage at the beginning of the test and continued with slight increases until a sudden significant increase in the potential was exhibited. The sudden increase in potential indicates an increase in the corrosion rate (Lalvani and Zhang 1995). The increase in corrosion rate is attributed to the formation of corrosion–induced minor cracks that allow more electrolyte (NaCl solution) to penetrate through the concrete and reach the steel rebars, which definitely increases the corrosion probability.

The cell potential history (Figure 3) depicts the differences in the time of first crack initiation in the specimens, where the sudden increase in potential started at day 12 in the control specimen, at day 15 in MS-0.5-C specimen, and at day 21 in MS-0.75-C. As long as the cell potential discussion is considered, the addition of fibers clearly affects the corrosion rate by delaying the corrosion–induced crack formation. Furthermore, it is clear that the cell potential values throughout the experiment are generally higher in the control specimen. Even after all specimens have cracked, the voltage in the control specimen kept on dominating the voltage in the rest of the specimens. This implies that the addition of fibers is effective in limiting the corrosion rate and development in such experiment.

![Graph of cell potential history](image)

**Figure 3.** Cell potential history of the corroded slabs.

### 3.2 Load-deflection Response of Slabs

To emphasize the effect of corrosion on the punching shear behavior of the tested slabs, a comparison between the load-deflection responses of the corroded and un-corroded specimens is presented in Figure 4.

![Load-deflection curves](image)

**Figure 4.** Load-deflection curves for all slabs.
For the control specimen, the corrosion of rebars resulted in a significant loss in the punching shear capacity of the slab, demonstrated in a 16% drop in the peak load in addition to a reduction in the deflection capacity. The deflection capacity, i.e., the deflection at the peak load was reduced by 36.2%. In terms of the residual strength of the slab, the corrosion resulted in a reduced post-peak strength. In the MS-0.5 specimen, the corrosion also resulted in a 19.1% less load-carrying capacity and 20.2% less deflection capacity. However, the corrosion resulted in a hardly considerable loss of strength post peak. For the MS-0.75 slab, the corrosion affected the slab less than the MS-0.5, where a 10.7% reduction in the punching shear strength and 22% less deflection capacity were experienced, all compared to the control specimen. The post-peak behavior of MS-0.75 specimens, both the corroded and un-corroded, was very similar; clearly in this specimen the corrosion had not impact on the strength residual.

Figure 5 compares the load-deflection response of all corroded slabs, i.e., the control with the MS fiber slabs. It is apparent that the increase in the MS fiber dosage from 0.5 to 0.75% resulted in no appreciable improvement, where the curves of both MS-0.5-C and MS-0.75-C specimens are similar in terms of cracking, peak load, and post-crack residual. All MS fiber slabs outperformed the Control-C specimen in terms of the general load-deflection behavior. Nevertheless, considering the residual strength capacity, it can be said that MS fibers improve the reliability of the slabs. The major advantage of MS fibers over the control is the gentle drop in the load-carrying capacity post peak, which demonstrates a safer behavior in the case of failure.

4 CONCLUSION

In this study, the effect of reinforcement corrosion on the punching shear of RC flat slabs incorporating synthetic fibers was investigated. Large-scale RC flat slab specimens were prepared with various synthetic fiber dosages to address their influence on the behavior of the slabs in punching shear. The following listed points are the main findings:

- The reinforcement corrosion greatly affected the punching shear behavior of the tested slabs in terms of strength, deflection, ductility, strain capacity, and severity of damage.
- The addition of fibers influenced the rate of corrosion development in the specimens, where the significant change in cell potential was at day 12 in the control slab, whereas it happened at day 15 in the 0.5% MS fiber slab, and at 21 in the 0.75% MS fiber slabs.
- In general, the corrosion had no significant impact on the post-peak behavior of the FRC slabs, where the corroded slabs performed similar to the un-corroded slabs in terms of post-peak residual strength capacity.
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