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Effect of Surface Roughness on the Failure Mode of FRCM-Concrete Bond

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Abstract

Fabric Reinforced Cementitious Mortar (FRCM) has been recently used for strengthening applications as it provides an alternative for the repair of reinforced concrete structures. While there are many factors that alter the efficacy of this material, the composite behaviour of FRCM and the concrete substrate remains an area of concern. An investigation of the bond behaviour is compiled in this paper with an emphasis on surface preparation techniques and how they affect the failure mode and bond capacity. Eighteen concrete blocks (150 x 150 x 165 mm) were prepared and tested in a double shear setup with varying parameters. These include 1) roughening levels, i.e. concrete surface profile (CSP) as per the International Concrete Repair Institute (CSP 1 – smooth surface, CSP 3 – medium roughened surface and CSP 6 – rough surface); and 2) concrete strength (normal strength of 30 MPa and high strength of 60 MPa). Results indicated that an increase in surface roughening altered the failure mode, however a lower level of roughening may be adequate as opposed to the current guidelines. It was also found that concrete strength had no effect on the bond capacity or failure mode.

Keywords: Fabric reinforced cementitious mortar (FRCM); Textile reinforced mortar (TRM); Concrete strengthening and repair; Surface roughness; Surface preparation; bond (FRCM-concrete)

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1.0 Introduction

External strengthening systems such as fabric reinforced cementitious mortar (FRCM) have been recently introduced to the construction industry to provide a relatively inexpensive strengthening solution as well as increase longevity of existing structures [1] [2] [3]. FRCM is a composite material comprised of fibres aligned in a grid (fabric) and cementitious matrix (mortar) that when bound together to the surface of concrete forms the FRCM system. Compared to other strengthening systems, the inorganic mortar has a better fire resistant, with increased chemical and physical compatibility with concrete substrate, as well is non-toxic [4]. Due to the nature of externally applied strengthening systems, the use of such materials creates potential for debonding failure. There are four types of debonding failure behaviours observed with FRCM; interlaminar debonding (matrix and fabric), FRCM debonding (matrix and substrate), slip (fibres pull from matrix), and delamination (cover loss) [3]. The FRCM-concrete bond problem was studied by several researchers [3, 7]. The studies focused on the effect of the number of layers, the bonded area (length and width of the sheet), the material type, the anchorage and the temperature. However, bond failures may occur due to poor application, inadequate surface preparation, poor compatibility between fibres and mortar and environmental impacts [4]. With FRCM debonding specifically, the problem lies with proper application and surface preparation, which can be hard to control at onsite applications [2]. The ACI 549 [5] guideline suggested that the concrete surface profile (CSP) as per the International Concrete Repair Institute (ICRI) [6] profiling system should be between 6 and 9. However, no quantified testing has been done specifically on surface preparation and how it may affect overall bond performance. In this paper, various levels of surface roughening will be analyzed on how it affects the failure mode of FRCM strengthened concrete with different compressive strengths.

2.0 Methodology

In this study, concrete blocks (150 x 150 x 165 mm) were tested with three levels of surface roughening (CSP of 0: "smooth", 3: "medium" and 6: "rough") and two concrete strengths (30 MPa and 50 MPa). Three repeats were made for a total of 18 specimens tested (Table 1).

Table 1: Test matrix and results

Specimen	P_u	FM	τ_u	Specimen	P_u	FM	τ_u	Specimen	P_u	FM	τ_u
S50-1	15	DB	0.82	M50-1	30	RF	1.64	R50-1	24	RF	1.33
S50-2	21	RF	1.17	M50-2	22	RF	1.24	R50-2	22	RF	1.21
S50-3	4	DB	0.22	M50-3	14	ID	0.79	R50-3	24	DB	1.31
S30-1	15	DB	0.84	M30-1	13	RF	0.71	R30-1	19	RF	1.08
S30-2	18	DB	0.99	M30-2	24	RF	1.31	R30-2	11	ID	0.60
S30-3	27	DB	1.48	M30-3	22	RF	1.22	R30-3	23	RF	1.25

S – CSP 0, M – CSP 3, R – CSP 6, 50 – (50 MPa), 30 – (30 MPa), P_u - ultimate load (kN), FM – failure mode, τ_u – bond strength (MPa).

2.1 Materials

The unidirectional carbon FRCM (C-FRCM) consisted of commercially available fabric and mortar. The composite properties, as provided by the manufacturer, were as follows: ultimate tensile strain 1.2%, ultimate tensile strength 875 MPa, cracked tensile modulus 1,330 GPa and the mortar shear bond strength 1.7 MPa.

2.2 Specimens Preparation

The concrete blocks were prepared at the UBC School of Engineering Structures lab. After 28 days of curing, the specimens' surface was roughened and the FRCM was applied. Figure 1 shows an example of the specimens' roughening level. Surface roughening was completed with a sandblasting cabinet for level 3, and a pressurized abrasive blaster with copper steel slag for level 6. The FRCM strips were cut into lengths of 800 mm, to allow 150 mm of bonded length on each side of the blocks and 500 mm free length for the test setup. Concrete was soaked prior to the FRCM application. The application of FRCM followed the supplier guidelines (Figure 2).

2.3 Test Setup

The specimens were axially loaded in a double shear test with steel plates connected to grips in the test machine (Figure 3). A curved support on the top plate helped to avoid localized stress points along the fibres, and uniformly distribute the loads to the bonded regions. The fabric was pulled simultaneously at approximately 2 mm/min until failure was detected.

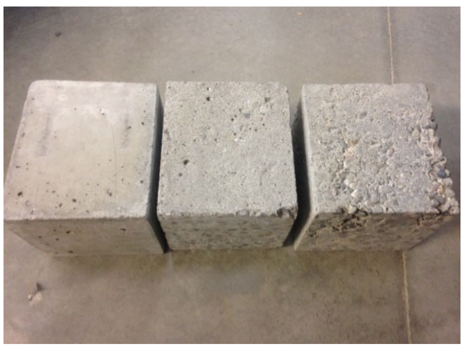

Figure 1: CSP 0, 3, 6 (left to right)

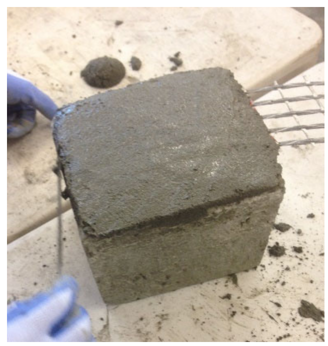

Figure 2: FRCM Application

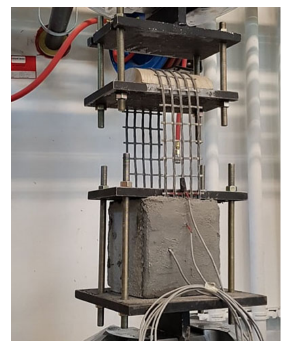

Figure 3: Test Setup

3.0 Results and Discussion

There were three failure modes observed in this study, 1) interlaminar debonding (ID), 2) FRCM debonding (DB) and fabric rupture (RF). Peak shear stress, (bond capacity, MPa), was calculated by dividing the peak load (kN) by two times the bonded area. The values of maximum load (P_u), stress (τ_u), and failure mode (FM) are shown in Table 1.

As expected, Specimens with CSP of 0 (smooth surface) had dominant debonding failure, with one exception of the C50-2 sample which exhibited fabric rupture failure. Specimens with CSP of 3 and CSP of 6 had dominant fabric rupture failure, with few exceptions. Specimen R50-3 had the mortar cracking during the test, causing the debonding prior to rupture. Overall, the results exhibited a correlation between increasing surface roughness and altered failure modes. During testing, it was observed that slight cracking sounds initiated due to a few premature broken fibres. This explains the variations in peak load of the ruptured samples, which was on average 22 kN, with standard deviation of 4 kN. For example, specimen M30-1 exhibited very low peak load, however the failure mode was deemed as pure rupture. Apart from C50-3 which was a full plate debond, it was also observed that all samples eventually ruptured either immediately after or simultaneously to bond failures. Additionally, the change in concrete strength does not affect the bond capacity or failure mode.

4.0 Conclusions

The following conclusions can be drawn from this experiment

- Of the 6 debonding failures, 5 were with CSP 0 and 1 with CSP 6. This suggests that increasing the roughening level decreases DB failure mode.
- Only 2 interlaminar debonding failures were present (with CSP of 3 and 6). This suggests that surface preparation has no effect on this failure type.
- Concrete strength had no effect on the peak loads or failure mode.

This study shows some promising results with the efficacy of surface preparation. While a CSP level 6-9 may be currently required, the results of this study has proven that a CSP level 3 is adequate to avoid bond failure. This is promising as surface roughening by means of sandblasting are costly, disorderly and required materials. Any way to minimize this effect while maintaining good bond is admirable for future use of this strengthening system.

5.0 Acknowledgements

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6.0 References

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