Thermo-mechanical analysis of Fibre reinforced cementitious matrix (FRCM) systems

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Abstract
FRCM systems are relatively new, and are made from different materials i.e. glass, aramid, steel and carbon. The mesh of this system is formed from fabric nets and cementitious mortar components which are functioning as a binder and matrix. FRCM systems perform better than FRP at elevated temperatures. To investigate the performance of FRCM systems under elevated temperatures, several FRCM-strengthened concrete beams were heated up to a controlled temperature of 280 ^{o}C, followed by mechanical loading till failure. The results indicated a much higher residual strength compared to FRP-strengthened systems, which completely de-bonded around 120 ^{o}C. The main reason is the cementitious mortar used in the application of FRCM, which is a high thermal resistance adhesive, instead of the epoxy resin used in the FRP composite applications.

The study continued by developing a finite element model to further observe the response of FRCM-strengthened specimens, particularly under thermo-mechanical loads. Several parameters were studied, such as the FRCM material type, FRCM thickness, and temperature level. The research confirmed the viability of FRCM systems used as alternative to their FRP counterparts, especially at elevated temperatures.

Keywords: FRCM, Carbon/ steel net, Temperature, Thermo-mechanical loading, Resin.

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Introduction

Fibre composite materials i.e. FRP, FRCM and TRM, are usually used for strengthening, repairing and retrofitting newly built or historical structures that are mainly externally bonded to the structure with the help of mortar or epoxy adhesives. Reinforced matrices and textiles are made from unidirectional and bidirectional fibres that are investigated by [1] to be used for strengthening and repairing of existing and/or newly built structures. The construction refurbishment materials and methods used for structural strengthening vary according to the suitability of the composites to the structures applied on and also the condition i.e. harsh environment and high temperature.

The widely known strengthening materials are Fibre Reinforced Cementitious Matrix (FRCM), Fibre Reinforced Polymers (FRP) and Textile Reinforced Mortar (TRM). These systems are manufactured differently as TRM and FRCM systems are applied with inorganic cementitious mortar, unlike FRP which uses epoxy in the application therefore the earlier named systems have outperformed FRP composites especially under elevated temperature due to their inherent non-combustibility or perhaps their superior strength retention [2].

FRCM and TRM techniques two of the main structural strengthening systems that attracted research engineers' attention, most especially in the last few decades. An experimental research carried out in [3] was successful in achieving a substantial improvement in the strength capacity of the beams strengthened with TRM. The strengthening materials are made to increase shear and flexural capacities of masonry and reinforced concrete structures and obtaining higher fire resistance due to the inorganic mortar used in the applications [4], [5].

Further, TRM and FRCM systems have become an effective alternative that have replaced FRP materials for strengthening and retrofitting of masonry walls [6, 7, and 8]. Other studies showed that the shear capacity of RC beams increased when FRCM materials was used as an alternative to FRP composites [9]. FRCM systems improved the ductility resistant due to the combination of textile and cement based matrix in production applied with mortar [10].

Laboratory test settings and results

In this research, beams were tested under four point bending (Figure1a) for unreinforced and reinforced concrete specimens. The testing was initiated with a load control step up to 5 (kN) which was controlled from the load cell system, then changed to a displacement control mode at a loading rate of 0.002 (mm/s). The data was automatically recorded by the computer system connected to the load cell. The experiment involved testing a total of fourteen small and large scale beams. Table (1) contains the summarised FRCM materials and beam parameters. At room temperature, twelve of the small and large size beams were tested and two of the large scaled specimens were tested at elevated temperatures above 280 ^{O}C (a specific temperature-controlling system was made to uphold the heat rise of the ceramic heater plate used in this study at City, University of London. Figure 1[b & c] shows the temperature test set up and temperature controlling system.

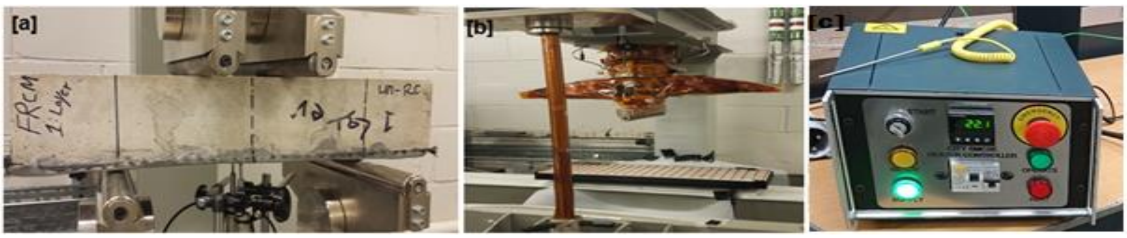

Figure 1: [a] RC specimen strengthened with one FRCM layer under four point bending, [b] Loading machine and ceramic heater plate, [c] temperature-controlling system (City, University of London).

For the unreinforced concrete control beam, a sudden failure occurred at an average loading of 10.81 (kN), and a flexural failure was recorded. The failure mode compared to the strengthened specimen was quite different due to the effect of the cementitious mortar and the fibre mesh present in the strengthening system. For the concrete specimens strengthened with one and two layers of FRCM carbon (Figure1a), the strength increase was 1.53 and 1.67 times that of the control specimen strength respectively, Figure 2 shows the experimental results obtained which the load capacity increased up to 17.8 kN when 2 layers of FRCM are applied. The beam strengthened with FRCM Steel Net system had a strength capacity raised by 3.8 times that of the initial control beam.

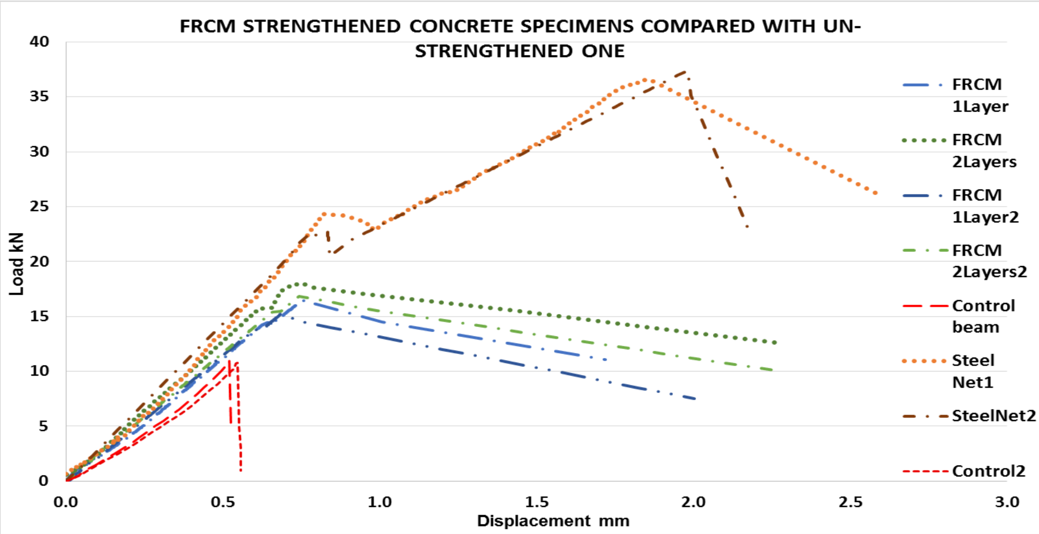

Figure 2: Load vs deflection experimental results (City, University of London)

The RC beam strengthened with FRCM carbon layer was able to withstand the loading up to 30 (kN) before the first crack was noticed, and no early cracks were observed before then. As loading continues, the number of cracks until a load of 67 kN where yielding was observed. The specimen failed at a load of 71 kN. In general, the cracks were more distributed due to the effect of the FRCM strengthening system present. Also, the crack widths were reduced compared to the control specimen. The strength capacity increase was about 1.3 times the capacity of the control beam. Fibre pull-out of the mortar was noticed but no rupture failure was recorded. When heated to a temperature of 294^{o}, cracks were observed at a load level of 23kN, yielding appeared at a load of 55kN, and the failure occurred at a load of 64kN. This constitutes a moderate decrease in strength due to the effect of elevated temperature, confirming the efficiency of FRCM systems under harsh environment.

Table (1): FRCM, reinforced & un-reinforced concrete beams parameters details

Flexure test Simply supported beams	Beam length and Clear span	Cross section height and depth	Longitudinal reinforced steel rebar & diameters	Stirrups and spacing
6 Reinforced concrete beams	1900 mm 1500 mm	250 by 150 mm	Top: two 10 mm bot: two 12 mm	10 mm plus 103 mm spacing
8 un-reinforced concrete beams	500 mm 300 mm	100 by 100 mm	No reinforcement	-
FRCM materials	tensile stress at 7.5% strain kN/m	Nominal thikness mm	Elongation at break tensile strain %	Ultimate tensile stress MPa
Carbon/Steel net	115 / 653	0.061 / 0.27	1.8 / 1.6	4700 / 2400

Conclusions

The conclusion remarks from this research and previous studies are:

- The FRCM systems have a great potential for the improvement of the concrete member strength, ranging from 15% up to 91% compared to the unreinforced control specimen, and up to 3.8 times the initial load capacity of the unreinforced concrete specimens.
- FRCM systems have a great influence on the failure mode, which was mostly due to de-bonding of the fibres which pulled-out from the mortar. Also de-bonding within the matrix at the interface of the fabric-matrix was observed. A delamination at the concrete surface was also noticed when the number of layers increased.

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References

[1] Triantafillou, T. C., Papanicolaou, C. G., Zissimopoulos, P. and Laourdekis, T. (2006). Concrete Confinement with Textile-Reinforced Mortar Jackets. ACI Structural Journal, 103(1), pp. 28–37.

[2] Fallis, G. J. (2009). Innovation for renovation: Cementitious matrix is used to bond high-strength polymeric mesh to concrete and masonry. Concrete International, 31(4), 62-64.

[3] Al-Salloum, Y. A., Elsanadedy, H. M., Alsayed, S. H. and Iqbal, R. A. (2012). Experimental and numerical study for the shear strengthening of reinforced concrete beams using textile-reinforced mortar. J Compos Constr. 16(1):74–90.

[4] Bisby, L. A., Stratford, T. J., Roy, E. C. and Ward, M. (2009). 'Fibre Reinforced Cementitious Matrix Systems for Fire- Safe Flexural Strengthening of Concrete: Pilot Testing at Ambient Temperatures'. In Advanced Composites in Construction (ACIC) 2009 Conference Proceedings. Net Composites Ltd., pp. 449-460.

[5] D’Ambrisi, A., Feo, L. and Focacci, F. (2013). Experimental analysis on bond between PBO-FRCM strengthening materials and concrete. *Composites Part B: Engineering*, 44(1), pp.524-532.

[6] Garofano, A., Ceroni, F., and Pecce, M. (2016). “Modelling of the in-plane behaviour of masonry walls strengthened with FRP grid reinforced mortar layers.” Composites Part B, 85, 243–258.

[7] Menna, C., Asprone, D., Durante, M., Zinno, A., Balsamo, A., and Prota, A. (2015). “Structural behavior of masonry panels strengthened with an innovative hemp fiber composite grid.” Constr. Build. Material, 100, 111–121.

[8] Parisi, F., Iovinella, I., Balsamo, A., Augenti, N., and Prota, A. (2013). “In-plane behavior of tuff masonry strengthened with inorganic matrix-grid composites.” Composites Part B, 45(1), 1657–1666.

[9] Papanicolaou, C. G., Triantafillou, T. C., and Lekka, M. (2011). “Externally bonded grids as strengthening and seismic retrofitting materials of masonry panels.” Constr. Build. Mater., 25(2), 504–514.

[10] Papanicolaou, C., Triantafillou, T., Papantoniou, I. and Balioukos, C. (2009). Strengthening of two-way reinforced concrete slabs with Textile Reinforced Mortars (TRM). In Proc. of the 4th colloquium on textile reinforced structures (CTRS4) und zur 1. Anwendertagung, SFB 528. Eigenverlag: Technische Universität Dresden. pp. 409–20.