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Bond Strength of NSM CFRP Textile and Concrete Using Modified Cement-Based Adhesive at High Temperature Site Exposure

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Abstract. Retrofitting of concrete structures has recently become a major issue worldwide due to design errors, earthquake damages and the deterioration by the exposure to the harsh environmental conditions, in addition to increase of loads carrying capacity of the structures. CFRP composites have been used efficiently to strengthening of concrete structures using epoxy adhesives to increase the service life of structures and increasing the applied loads. However, the limitations of using epoxy resin only at low temperature below the glass transition temperature, has created a need to replace the epoxy adhesives with cementitious bonding materials to provide better resistance at high temperatures environments. This program assessed the bonding between near-surface mounted (NSM) carbon fibre reinforced polymer (CFRP) Laminate and concrete using modified cement–based adhesive at site exposure in high temperature environment. The study showed a significant resistance of modified cement adhesive as a bonding material at high temperature environment compared to epoxy adhesive.

Keywords. Epoxy, cement-based adhesive, near surface mounted (NSM), CFRP Composites

1. Introduction

Over the last few decades, strengthening of concrete structures has been a subject of concern in civil engineering research to increase the structure life and carry the additional loads due to the degradation of mechanical properties of materials over time, the increases in the required service loads, and the updating of design codes of existing RC structures. This has led to develop new methods of strengthening techniques using CFRP composites. The epoxy adhesives played a major role in the strengthening technology due to providing excellent bonding properties between the CFRP and concrete substrate. However, the hazards of toxic fumes, skin irritation and the degradation of mechanical properties of the epoxy resins at elevated temperature, are some disadvantages associate with the use of epoxy adhesives [1]. Replacing the epoxy adhesives with cementitious bonding agent can enhance the performance of structures

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in high-temperature regions and minimize the environmental hazards [2-7]. The application of cement-based adhesive for externally-bonded FRP strengthening showed a premature delamination of FRP in the critical failure which reduces the effectiveness of the fibre to increase the loading capacity of members [8]. Near-surface mounted (NSM) strengthening system using cementitious bonding agent can provide a better anchorage system and bond strength [9]. In addition, the use of cementitious adhesive can enhance the performance of fiber at high temperature environment [10-13]. Modified cement-based adhesive for NSM technique provided excellent bond strength at normal and high temperature [14, 15, 16]. The assessment of the efficiency of this adhesive at elevated temperature has been conducted in this investigation. Pull-out testing of 7 concrete specimens was conducted using a single-lap shear test set-up at site exposure in high temperature environment. The test results showed significant performance of the NSM technique using modified cement adhesive at high temperature site exposure.

2. Experimental Program

This program was conducted to assess the performance of the modified cement-based adhesive under severe environmental conditions to provide an actual evaluation compared to the laboratory test results. The specimens were loaded to their design loads and subjected to harsh environmental conditions of high temperature and humidity. According to the statistical parameters of the temperature and humidity variations for three cities (Darwin and Cairns in Australia and Dubai in the United Arab Emirates (UAE) for the five years 2002-2006 (www.wunderground.com) [16], the UAE in the Middle East had the most severe environment based on the temperature and humidity in the summer season. The statistical analysis and temperature frequency distributions are described in the following paragraph (Figure 1).

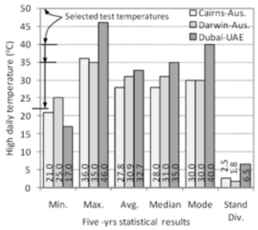

Figure 1. Statistical daily temperatures for 2002-2005 at selected locations (Abbas and Al-Mahaidi, 2010).

The test was conducted for 6 specimens stranghened with NSM CFRP laminate. Group of three was tested at normal teperature and group of three was exposed at high temperature exposure and tested under actual service loads. The specimens details is shown in table 1.

Table 1. Specimen details.

Specimen Details	Bond length (mm)	Number of specimens	Fibre section (mmxmm)	Groove depth (mm)
LC150-N	150	3	1.4 x 10	18
LC150-SE	150	3	1.4 x 10	18

L: Laminate, C: Cement-based, N: Normal Temperature, SE: Site Exposure

2.1. Specimen Details

The program included 7 concrete prisms strengthened with CFRP laminate using modified cement-based adhesive. The specimens were bonded with NSM CFRP laminate and had bond lengths of 150mm as shown in figure 2. Three specimens for normal test and four specimens were pre-loaded with design loads for the LC150 specimens according to AS1170 and exposed to direct sun exposure in high temperature environments during the Northern hemisphere summer season in the United Arab Emirates.

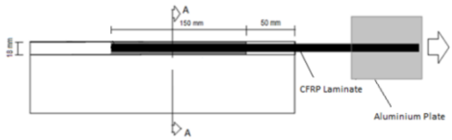

Figure 2. Specimen details of CFRP laminate at normal temperature test.

2.2. Specimen Preparation

The specimens of site exposure test were prepared following the same preparation method for strengthening of the specimens of normal temperature test, with the exception that the gripping was made of steel plate instead of aluminium to fit the preloading frame, as shown in figure 3. Specially-designed steel frames were used to provide permanent sustained load in the exposure regime during the entire test period. The frames were capable of sustaining applied loads without significant losses due to creep and relaxation of the system. Furthermore, the frames were designed to accommodate four CFRP-concrete specimens at different loading intensities. The basic frame elements are made of rigid box steel section 50mm x 50mm x 2.5mm with the dimensions of 850 mm wide and 495 mm high (see figures 4 and 5). The rigidity was required for the applied loads of 8.36 kN for each sample which could reach 4 x 8.36 kN, or 3.34 tons per frame.

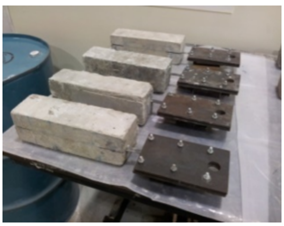

Figure 3. Cured specimens with gripping plates.

Figure 4. Preloading steel frames.

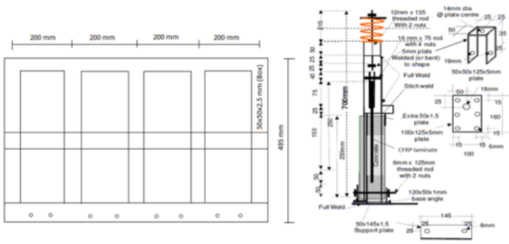

Figure 5. Permanent loading steel frame schematic.

2.3. Permanent Loading Spring

A special loading set-up was used to maintain constant tensile load on the CFRP during the test period. A spring was used to compensate the applied load for any losses resulting from change of dimensions due to creep, relaxation and temperature effect to maintain the load within an acceptable range of variation. The dimensions of the spring are illustrated in figure 6. The theoretical spring stiffness was 266.69 N/mm, as presented in table 2. However, since these springs were used previously in experimental work conducted at the American University of Sharjah, laboratory loading tests were carried out to obtain the springs' constant K. Calibration involved testing three springs, and the results showed a linear elastic behaviour of 205.8 N/mm, as shown in figure 7. This variation in the K was due to the long period of preloading under external exposure which may have affected the material properties.

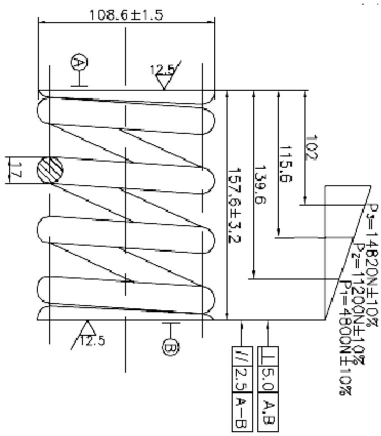

Figure 6. Spring geometrical details.

Table 2. Spring technical properties.

Material: Carbon steel valve spring wire EN 10270- 2 -VDC		
Surface treatment	Shot-Penned	
Direction of coil winding	Right	
Number of active coils	n	4
Spring constant (N/mm)	k	266.69
Spring weight (kg)	m	3.134
Outer spring diameter	De	108.59
Inner spring diameter	Di	74.59
Free spring length	L0	157.56
Preloaded spring length	L1	139.56
Fully loaded spring length	L8	115.56
Theoretic spring limit length	L9	102
Minimum working loading	F1	4800
Maximum working loading	F8	11200
Theoretical limit loading	F9	14817
Wire diameter (mm)	d	17

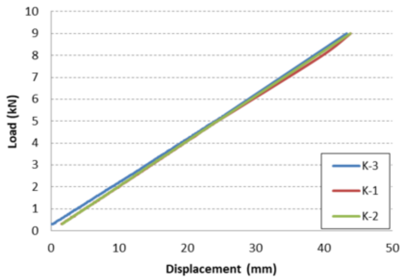

Figure 7. Calibration results for spring constant K.

2.4. Normal Temperature Test Results

LC150 Series, achieved an average ultimate load of 14.12 kN for three specimens with an increase of about 24% for specimen LC100. The average bond stress was about 4.12 MPa. The same failure pattern was observed with slipping of fibre due to the failure of the interfacial surface between the fibre and the adhesive. The load-displacement curves are plotted in figure 8.

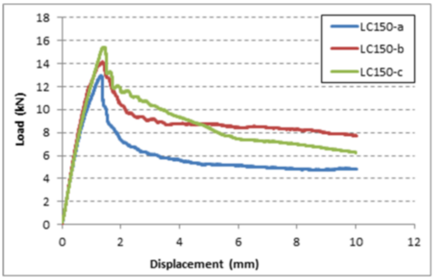

Figure 8. Load-displacement curves of LC150 specimens.

2.5. Pre-loading Method for Site Exposure Test

The pre-loading on the specimens was applied after 28 days of curing. The design load was calculated using the average ultimate load of 14.12 kN of LC150 specimens from the previous experimental results. The specimens were aligned with the loading centre. The loading was applied by tightening the top nut to compress the spring and provide tension on the steel rod up to the required distance equivalent to the applied design load of 8.36 kN. The shortening of the spring was controlled by digital vernia to ensure the application of the correct amount of load. The preloaded specimens in the frame are illustrated in figure 9. The design load was calculated according to AS 1170.0 as follows:

$$p^* = \varphi\, p_u \tag{1}$$

where: p^* is the factored load, p_u is the ultimate capacity (14.12 kN), and $\varphi = 0.8$.

With the assumption that the dead and live load are equal to each other and

$$p^* = 1.2G + 1.5Q \tag{2}$$

Thus: G = Q = 4.17 kN

The applied service load = 2 x 4.17 = 8.36 kN

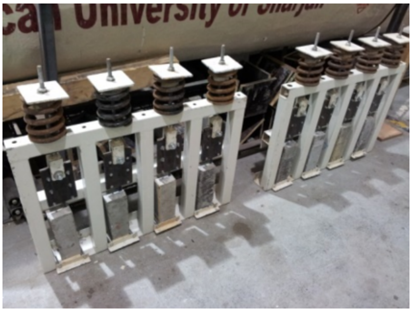

Figure 9. Specimens under permanent load.

2.6. Temperature Records at Site

The temperature at the site was monitored during the entire site exposure period. The temperature was recorded regularly at the surface of the specimens in various locations at critical times (12:0 noon and 2:0 pm). The concrete surface temperature was about 24% higher than the surrounding air and the CFRP temperature was lower than the concrete surface by 1.5-2°C. The maximum temperature recorded at the concrete was 62.3°C and in the CFRP 60.2°C.

2.7. Test Set-up

The single-lap shear test set-up was used in this program. The set-up was designed to fit the specimen dimensions since this set-up was used previously in the American University in UAE. Figure 10 shows the test set-up with a specimen under loading. The load was applied using a 50 kN Instron testing machine with a load-displacement rate of 0.2 mm/minute.

Figure 10. Experimental test set-up.

2.8. Site Exposure Test Results

After the site exposure period ended, the specimens were tested to assess their strength. The test results showed the efficiency of the adhesive under high temperature exposure since no failure of specimens during the entire exposure period occurred. The average ultimate load of specimens after completion of the exposure period was 16 kN, as illustrated in the load-displacement curves in figure 11. This value is higher than the normal test results due to ageing of the adhesive during the exposure period. The failure mode was at the interface between the fibre and the adhesive, resulting in slippage of the fibre, as shown in figure 12.

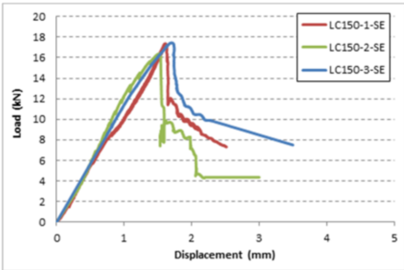

Figure 11. Load-displacement curves of specimens LC150-SE.

Figure 12. Failure mode of specimens LC150-SE.

3. Conclusion

This program has presented the procedure and test results of 6 single lap-shear specimens tested under normal and high temperature.The site exposure test to provide evaluation of the adhesive's performance under severe environmental conditions showed the possibility of applying the adhesive in regions of high temperature and humidity. The specimens with modified cement-based adhesive sustained the applied design loads during the exposure period under the highest temperature and humidity in the summer season.

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References

[1] Taljestin B, Blanksvard T. Mineral-based bonding of carbon FRP to strengthen concrete structures. Journal of Composites for Construction. 2007; 11(2): 120-128.
[2] Badanouiu A, Holmgren J. Cementations composites reinforced with continuous carbon fibers for strengthening of concrete structures. Cement and Concrete Composites. 2003; 25(3): 387-394.
[3] Hashemi S, Al-Mahaidi R. Investigation of bond strength and flexural behaviour of FRP strengthened RC beams using cement-based adhesives. In: Proceedings of the Structures Congress, Orlando (FL), 2010; pp. 689-700.
[4] Hashemi S, Al-Mahaidi R. Cement Based Bonding Material for FRP. Proceedings of the Eleventh International Inorganic-Based Fibre Composites Conference. Madrid, Spain, 2008; 5(7), pp. 267-271.
[5] Hashemi S, Al-Mahaidi R. Flexural performance of CFRP textile-retrofitted RC beams using cement-based adhesives at high temperature. Construction and Building Materials. 2012; 28(1): 791-797.

[6] ACI-440.2R. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. American Concrete Institute, 2008, U.S.A.

[7] Thanasis T, Stijn M, et al. Externally bonded FRP reinforcement for RC structures. Fib Bulletin. 2001; (14).

[8] Pham H. Debonding Failure in Concrete Members Retrofitted with Carbon Fibre Reinforced Polymer Composites. PhD thesis, Department of Civil Engineering, Monash University. 2005; pp. 136-149.

[9] Barros JAO and Fortes AS. Flexural strengthening of concrete beams with CFRP laminates bonded into slits. Cement and Concrete Composites. 2005; 27(4): 471-480.

[10] Gamage J, Al-Mahaidi R and Wong M. Bond characteristics of CFRP plated concrete members under elevated temperatures. Composite Structures. 2006; 75: 199-205.

[11] Kodur V, Bisby L. Evaluation of fire endurance of concrete slabs reinforced with fibre-reinforced polymer bars. Journal of Structural Engineering. 2005; 131(1): 34-43.

[12] Saffi M. Effect of fire on FRP reinforced concrete members. Composite Structures. 2002; 58(1): 11-20.

[13] Bisby L, Green F and Kodur V. Response to fire of concrete structures that incorporate FRP. Progress in Structural Engineering and Materials. 2005; 7(3):136-149.

[14] AL-Abdwais A, Al-Mahaidi R and Abdouka K. Modified cement based adhesive for NSM strengthening system. In: Proceedings of the Fourth Asia-Pacific Conference on FRP in Structures (APFIS), 11-13 December 2013; Melbourne, Australia.

[15] Al-Abdwais A and Al-Mahaidi R. Performance of NSM CFRP strengthened concrete using modified cement-based adhesive at elevated temperature. Construction and Building Materials. 2017; 132(1): 296-302.

[16] Abbas BM and Al-Mahaidi R. Durability of CFRP-concrete Bond under Sustained Load in Harsh Environment. PhD Thesis, Monash University, Australia. 2010.