Ain Shams University
Faculty of Engineering

BOND CHARACTERISTICS BETWEEN HIGH STRENGTH CONCRETE (HSC) AND CARBON FIBER REINFORCED POLYMERS (CFRP)

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A Thesis
Submitted in Partial Fulfillment of the Requirements
of the Degree of Master of Science in Civil Engineering (Structural)

Under the supervision of:

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Abstract of the M.Sc. Thesis Submitted by
Eng. / Ayman Ahmed Mahmoud Moustafa

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ABSTRACT

Use of fiber reinforced polymers, FRP in strengthening reinforced concrete elements, has increased rapidly in the last three decades. FRP is made of high-tensile-strength fibers such as carbon (CFRP), glass (GFRP), aramid (AFRP). FRP laminates (sheets and strips) are used widely to strengthen and repair different RC elements. FRP has an outstanding characteristic since it is corrosion free. This can increase significantly the service life of structures by reducing concrete deterioration. Other advantages of FRP laminates of particular interest in the field of structural applications are its high strength-to-weight ratio, good fatigue behavior, low relaxation, and easy handling and installation. The drawbacks of FRP reinforcement include its high cost, brittle failure, low shear strength, lack of ductility due its linear stress-strain behavior up to failure, and low tensile strain at ultimate.

Although the FRP has very high tensile strength, this is often not fully utilized due to the possible debonding between the FRP and the concrete surface under relatively lower loads. Debonding is one of the main problems regarding the use of externally bonded FRP strips. Several types of debonding may occur when strengthening concrete beams with FRP strips. These types can be generally divided into two main groups: i) plate end debonding; where the debonding occurs at the end of the strip, and ii) intermediate crack debonding; where the debonding occurs under the flexural or flexural shear cracks. This thesis aims to investigate the bond characteristics between high strength concrete beams and carbon fiber reinforced polymers, CFRP. The intermediate crack debonding is the major debonding failure mode.

An experimental program was conducted at the Reinforced Concrete Research Unit at the Faculty of Engineering, Ain Shams University to study the behavior of RC beams strengthened by CFRP strips. The program consists of testing eight simply supported beams with overall dimensions of 150 mm width, 300 mm depth and 3000 mm length, divided into four groups depending on different parameters. The first group consisted of three beams varying in compressive strength (specimens B1 to B3). The second group consisted of three beams varying in bond length (specimens B3, B4 and B6). The third group consisted of three beams varying in wrapping system (specimens B6 to B8). The fourth group consisted of two beams varying in concrete cover (specimens B3 and B5). The analytical phase of this study includes a rational analysis to predict the behavior of RC beams strengthened with CFRP strips at the tension side of the beam and GFRP sheets used as U-wraps. An assessment regarding some of the existing codes provisions and models from the literature to predict intermediate crack debonding was performed. Based on the experimental results of the tested beams and the analytical work, new parameters were proposed to predict the intermediate crack debonding failure for simply supported beams strengthened with CFRP strips.

Keywords: Bond, CFRP, Composite materials, Concrete structures, High strength concrete beams, and Intermediate crack debonding.

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STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Structural).

The work included was carried out by the author at reinforced concrete laboratory of the faculty of engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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LIST OF SYMBOLS

a = the distance between the support and the location of the acting load.

A_c = area of concrete.

A_{CFRP} = area of the CFRP laminates.

A_{GFRP} = area of the GFRP laminates.

A_s = area of the bottom steel reinforcement.

A_{sc} = area of the top steel reinforcement.

b_c = width of concrete beam.

b_f = width of FRP strip.

c = neutral axis depth from the compression fiber.

d_s = depth of the bottom steel reinforcement from compression fiber.

d_{sc} = depth of the top steel reinforcement from compression fiber.

d_{CFRP} = depth of the CFRP laminates from compression fiber.

d_{GFRP} = depth of the GFRP laminates from compression fiber.

E_c = elastic modulus of concrete.

E_{CFRP} = elastic modulus of CFRP laminates.

E_s = elastic modulus of steel reinforcement.

f_c = concrete stress in compression.

f_s = stress of the bottom steel reinforcement.

f_{sc} = stress of the top steel reinforcement.

f_{CFRP} = stress of the CFRP laminates.

f_{GFRP} = stress of the GFRP laminates.

k_c = factor accounting for the state of compaction of concrete.

k_m = reduction factor for the debonding strain in the FRP.

L = the beam clear span.

M = bending moment.

$N_{fa,max}$ = the maximum FRP force which can be anchored.

P = the acting load on the beam.

P_{max} = maximum load.

P_y = load at yielding of bottom steel reinforcement.

y = distance, measured from the neutral axis.

ε_{sc} = Maximum measured compression strain in top steel reinforcement.

ε_{st} = Maximum measured tensile strain in bottom steel reinforcement.

ε_{cu} = ultimate strain of the concrete in compression.

ε_{fd} = debonding strain of the CFRP strip.

ε_{s} = strain of the bottom steel reinforcement.

ε_{sc} = strain of the top steel reinforcement.

ε_{CFRP} = strain of the CFRP laminates.

ε_{GFRP} = strain of the GFRP laminates.

Δ_{u} = deflection at failure load.

α_{1}, β_{1} = stress block factors.

α = reduction factor to account for the influence of inclined cracks on the bond strength.

λ_{a} = factor to take into account the effect of U-wraps.

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