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FULL LENGTH ARTICLE

Efficiency of coating layers used for thermal protection of FRP strengthened beams

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Abstract This paper investigates the efficiency of coating layers used for thermal protection of Fiber-Reinforced Polymer (FRP) strengthened Reinforced Concrete (RC) beams.

An experimental program was carried out on 36 RC beams protected by using different coating layers of Perlite, Vermiculite, Portland Cement (PC) mortar, clay and ceramic fiber. The tested beams were exposed to 100, 200, 300, 400, 500, and 600 °C for 2 h, left to cool gradually, then tested to failure. The obtained results demonstrated that exposure to elevated temperature without protection reduces the residual flexural strength of RC beams by 20–66%, depending on the degree of temperature. Protecting RC beams by a 30 mm-thick layer of the tested materials was demonstrated to be efficient in reducing heat transfer through 2-h exposure to 600 °C, and thus provide higher fire rating. Protection layers of cement mortar, Aswan clay, Vermiculite, Perlite and ceramic fiber blanket, showed residual flexural capacity equal to 61%, 68%, 72%, 73% and 74% that of the control beam, respectively. Moreover, using double coating layers of ceramic fiber followed by Perlite plaster, Vermiculite plaster, PC plaster or Aswan clay, with overall total thickness of 50 mm was demonstrated to give better protection, and maintain residual flexural capacity only 5% less than the flexural capacity of control beams.

Introduction

In the recent years, there was a strong need to repair/strengthen concrete structures due to material deterioration, environmental effects, misuse or overloading. As an alternative to traditional strengthening techniques, Fiber-Reinforced Polymers (FRP) are being increasingly used due to their desirable attributes. Although FRP strengthening proved efficiency in practice, there are increasing concerns related to their performance in case of fire. Polymer materials exhibit a change in mechanical properties when exposed to temperature higher than 80–120 °C, referred to as the glass transition temperature (T_g). This causes serious damage to the bond between the FRP and the concrete surface and consequently the structural integrity and effectiveness of the FRP strengthening will be severely threatened or may be totally lost.

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Some design codes such as ACI 440-2008 [1] do not recommend the use of FRP internal or external reinforcements for structures in which fire resistance is essential. Other codes limit strengthening by externally bonded FRP to only 40% of the capacity, for the unstrengthened concrete element to be sufficient to resist the service loads [2].

Elevated temperature conditions occurring in case of fire have damaging effects on concrete structures [3]. Temperature rise between 100 and 200 °C causes the free moisture contained in the concrete mass to evaporate and thus the high internal steam pressure generated may cause spalling of concrete [3]. The reduction in concrete compressive strength may reach 15–40% and 55–70% of its original value for concrete when exposed to elevated temperature of 300 and 600 °C, respectively [4,5]. Concrete samples subjected to 600 °C for 2 h in a closed furnace, cooled slowly in air and then tested to failure gave compressive, tensile and flexural strengths of 56%, 31% and 18% of the control specimen, respectively [6].

Previous researches investigated the effect of elevated temperature (fire) on FRP-strengthened RC elements [6–12]. For strengthened RC beams with externally FRP laminates, a sufficiently high shearing force must be developed and transferred by the interface layers between concrete and FRP laminates. This shearing force is usually carried by adhesive polymers which are subjected to loss of strength when subjected to high temperature exceeding its glass transition temperature (T_g) which ranges from 80 to 120 °C for most commercial polymers [7–10]. Attempts to protect the FRP externally bonded laminates using protective paints supplied by FRP manufacturers was reported to show only slight protection and enhancement of residual strength of the strengthened elements not exceeding 5% [6,11]. More successful results were obtained through the use of coating layers of thermal-resisting materials such as Perlite, Vermiculite, Perlite-gypsum plaster and Rockwool [6,13,14] or by using ceramic fiber sheets followed by one of these layers [15,16].

The significance of the present paper is based on current research needs to enhance the performance of FRP-strengthened elements in case of exposure to elevated temperature or fire.

Experimental program

The experimental work consisted of testing 36 RC beams, strengthened externally by FRP and protected with different coating layers. The beams were subjected to various elevated temperatures for 2 h, left to cool gradually and then tested in flexure till failure to evaluate the residual strength [16]. All tests in this research were carried out in the Concrete Laboratory of Housing and Building Research Center. The materials used and procedure of preparing, casting, curing, strengthening and thermal protection of the tested specimens are briefly presented in this section, as well as the testing procedures.

Materials

Concrete

The mix proportions for concrete used for casting all specimens are given in Table 1. The cement used is the Portland Cement satisfying the Egyptian Standard Specification ESS 4756-1/2009 [17]. Coarse aggregate used is washed crushed limestone of nominal maximum size of 20 mm, fine aggregate is clean natural siliceous sand nearly free from impurities, both satisfying the Egyptian Specification E.S.S 1109/2008 [18], and are properly graded. Drinkable clean water, fresh and free from impurities is used for mixing and curing the tested specimens. The average concrete compressive strength used was 25 MPa.

Steel reinforcement

Mild Steel bars 8 mm in diameter with yield stress of 280 MPa and ultimate strength of 410 MPa were used as main longitudinal reinforcement and stirrups for all tested beams.

FRP strengthening

External strengthening of the RC beams was made by sheets of EG-900 unidirectional S-glass fibers (GFRP) of width 610 mm, thickness 0.373 mm/ply and unit weight 900 g/m^2, having ultimate tensile strength 1517 MPa, modulus of elasticity 72.4 GPa and ultimate strain 2.1% [19]. Two-component epoxy adhesive was used for applying GFRP sheets on the bottom surface of RC beams.

Glass fibers

Glass fibers were added to concrete or mortar to minimize shrinkage. Alkali resistant chopped strand fibers produced from 100% coated fiberglass were used. These fibers are 17 micron in diameter, 12 mm in length and characterized by its low thermal conductivity. The manufacturer suggests 0–5 kg of fibers for every 50 kg of cement.

Air entraining admixture

Micro-Air100, an ASTM C-260 air-entraining admixture was used. This product is a brown liquid of a specific gravity of 0.9886 and pH of 10.5–12.5. It creates stable air bubbles that are small and closely spaced, thus decreasing the thermal conductivity of paste.

Table 1 Mix proportions of concrete mix used to cast all beams.

Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Water (l)
400	1470	735	200

Table 2 Mix proportions of 1 m^3 of mortars used as protective layers.

Layer	Perlite (l)	Vermiculite (l)	Clay (l)	Sand (kg)	Cement (kg)	Water (l)	Fiber (g)	Air-entrained admix (l)
PC mortar	–	–	–	1600	500	200	900	4
Perlite mortar	1 m^3	–	–	–	500	330	900	4
Vermiculite mortar	–	1 m^3	–	–	500	415	900	4
Aswan clay	–	–	1 m^3	–	500	500	1800	4