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Sustainability of Carbon Fiber Reinforced Concrete Beams Sunder Sea Water Splash Zone

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ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) has found great applications in the building and construction industry. However; there is a limited theoretical and experimental research in this area. This report investigates the durability of the bonding between external CFRPs and the concrete. Partially loaded CFRP concrete samples at various load intensity were subjected to several sets of environmental exposure conditions. The studied parameters include actual marine environment (provided by AUS and placed in the Construction Materials Lab), loading effects, humidity and moisture, high thermal effects, and ageing tests. The main purpose of this project is to develop a method for estimating the reduction in bond properties due to combinations of the above exposures that are used as a degradation measures. The design team utilized the various relevant courses studied at AUS in structural and material areas to achieve our goals. The obtained results will provide new systematic technical data on the structural properties and long term behavior that will enable proper application of CFRP in UAE structures. Preloading Failure is shown in three specimens out of 12 specimens. One of them was in open dry environment and the other two were in the splash zone. Comparing the higher loaded specimens with the lower loaded ones of the same exposure type, it was found that the higher sustained loaded ones have higher deformation. Observing the failure deformation of specimen in different environmental exposure, the more severe the environment, the more deterioration in bond properties. Higher temperature exposure caused material brittleness and failure in the bond.

Keywords: *CFRP, Sea Water Splash Zone, High Temperature, Sustainability, Bond Stress*

1. INTRODUCTION

Electrochemical corrosion of steel in various concrete structures has become a serious issue all over the world. “In Canada, it is estimated that the required repair cost for parking garages alone is in the range of $6 billion and in U.S, for all concrete structures, the rehabilitation cost is estimated to exceed $250 billion per year” [1]. Therefore, it would be reasonable and highly demanding to be concerned and to prevent such corrosion-related deterioration, which could save the billions of dollars required to deal with steel corrosion problems. A very recent step in that direction, which has received global attention, is the use of FRP (Fiber Reinforced Polymer) composites as a cost effective alternative to traditional construction materials and techniques. FRP plates can be at least twice but as 10 times as strong steel plates, while their weight is only 20% of that of steel.

FRP composites are formed by embedding continuous high strength multilayer reinforcing fibers in a resin matrix, which binds the fibers together as illustrated in Figure1. The most commonly available FRPs, which can be used for civil infrastructure, are glass (GFRP), carbon (CFRP), and aramid (AFRP).

Epoxy resins, polyester resins and vinylester resins are the common resins. The main function of fibers is to carry load, while the matrix holds the fibers together and protects them from mechanical and environmental effects. The composite materials acquire its properties, such as strength, durability, thermal conductivity, etc from embedded fibers and surrounding matrix.

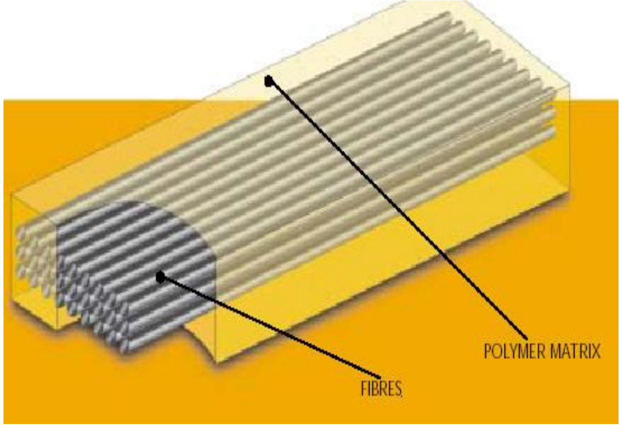


Figure 1: Composition of FRP, Ref [1]

2. FRP APPLICATIONS

FRP composites have a successful history of application in the aerospace, marine, space, and chemical industries. The limited use of these materials in civil engineering applications has been due to their high cost. Their prices have been coming down rapidly, enabling their wider applications in civil engineering [3]. Also, recent experimental and analytical research all over the world, has led to extensive progress in their use in civil infrastructure ranging from internal reinforcement (eg. reinforcement bars), external reinforcement (eg. plates for strengthening of walls, beams, and slabs), and composites bridge decks. We will conduct our studies on externally bonded CFRP to concrete beams.

3. FRP DURABILITY PERFORMANCE

Although FRPs are resistant to electrochemical corrosion, the performance of FRPs may deteriorate due to environmental, physical or chemical conditions, leading to loss of strength or stiffness. There is a small, but growing, body of research, which is specifically concerned with the durability of FRP composites in civil infrastructure applications[4] defined durability as, “ the ability of the material to resist cracking, oxidation, chemical degradation, delamination, and wear, for a specific period of time, under the appropriate load conditions, under specified environmental conditions.” Due to the addition of FRP composites to concrete structures, the durability performance of FRP reinforced concrete structures becomes more complex due to the combined effect of FRP composites, interface, and various environmental and mechanical conditions. To focus on the complexity of the analysis, attention is restricted to the following durability influence factors: 1.extreme environmental temperatures, 2. humidity and saturation, 3. chemical solution and sea water, 4. aging, 5. sustained load.

It is necessary to investigate the combined effect of the above exposures since there is interaction in their effects. FRP reinforced concrete members can exhibit a complex viscoelastic behavior due to the combination of the viscoelastic behaviors of the concrete, the adhesive, and the FRP composite. Thus, the apparent stiffness and strength of FRP composites will decrease slowly over time. Creep is one example of the complex interaction between the different factors. When a material is subjected to a constant applied stress, the material will exhibit a time-dependent strain, known as creep. Loading cause cracks in the concrete and the adhesive layer. Those cracks eventually accelerate the entrance of water into the interface. Furthermore, the thermal cycles increase creep rates in the adhesive leading to creep fracture of the adhesive, causing further moisture ingress. Fluid absorption in FRP composites will lead to residual stress and plasticizing of the resin, which can accelerate the time-dependent behavior of FRP composites [5].

Bonding between FRP and concrete is important for structural integrity of both FRP internally and externally reinforced concrete structures. The durability of FRP external reinforcement can basically be determined in the same way as for FRP internal reinforcements. However, durability related to bond performance in concrete is different. In general, although the literature is limited in this research area, and conclusive results have not been achieved, some studies are being conducted to identify the effects of the environmental conditions and mechanical conditions and their combined effects on bond behavior.

The effects of acidic and alkaline conditions under varying and constant temperatures, on bond in concrete beams wrapped with carbon fiber sheets were studied by [6]. The results showed acidic exposure led to 17% decrease in bond shear strength while alkaline exposure led to a 24% decrease in bond shear strength. Myers et el [7] studied the bond durability of concrete beams externally bonded with CFRP sheets. The specimens were exposed to two different environments: room temperature (20 C) and 300 wet-dry cycles (salt water was used for the wet cycles) and the dry cycles were at 35 C and 90% humidity. Wet-dry cycles led to the degradation of epoxy, which reduced the bond between the FRP sheet and the concrete [8]. Unreinforced concrete beams, 90mm X 90mmX 600mm, were prepared. In one group of beams, CFRP rods were embedded in epoxy resin in a longitudinal slot cut in the concrete. In the second group, CFRP sheets were glued to the surface of beams with epoxy. One group was exposed to one cycle at - 23 C. Other groups were exposed to cyclical temperature in an environmental chamber from -23 C to 60 C every 4 hours. In addition, two groups were exposed to a continuous salt fog of 46 C for 1 year. Exposure of the test specimens in a differential temperature of 83 C for 762 thermal cycles did not lead to visible cracking. After 1188 cycles, all of the samples strengthened with CFRP rods contained visible cracks in the concrete adjacent to the groove filled with epoxy. Exposure to the 46 C salt fog conditions did not result in any visible deterioration of the bond in any of the samples [8]. The load carrying capacity of beams strengthened with CFRP plates with and without end anchorage increased by 5%-80% compared to that of the control beam [9].

Actually, we can see from the literature review that there was no consistent testing methodology or parameters that exist on the bond strength of CFRP-concrete under the combined effect of loads, cyclic temperature and humidity. Therefore, it is essential to verify more the durability performance of the bond between the FRP and the concrete in order to apply it successfully in UAE structures.

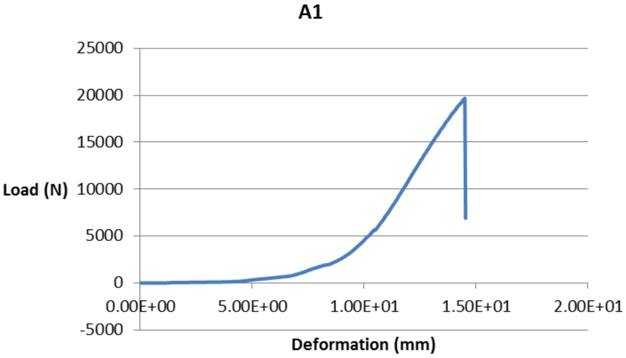
Overall, the design focus will be on the durability performance of the bond between externally bonded CFRP to concrete beams and limited to the following factors 1.extreme environmental temperatures, 2. humidity and saturation, 3. Chemical solution and sea water, 4. aging, 5. sustained load.

4. EXPERIMENTAL METHODOLOGY

The lab control frame consists of four specimens: A1, A2, A3, and A4. All of the specimens were tested and the test results are presented below.

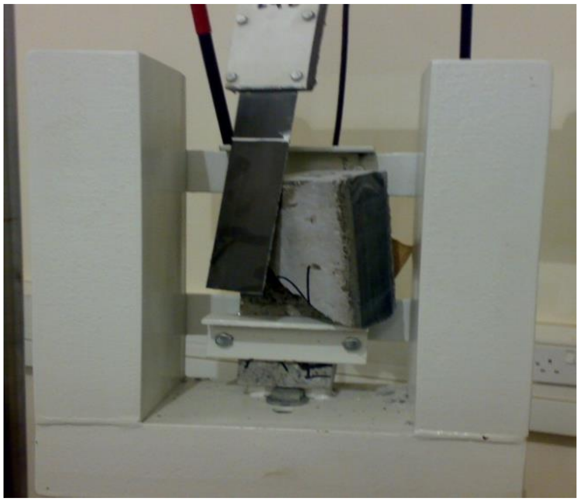
Test 1

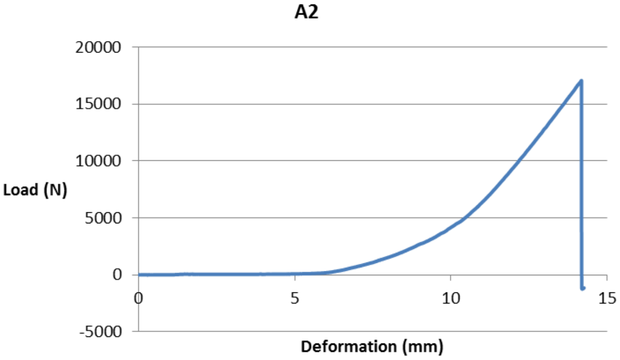
Specimen	A1
Exposure Type	Lab
Load	10 kN
Failure displacement	14.498 mm
Bond Stress	2.62 MPa
Failure Mode	Mode 2 Concrete



Test 2

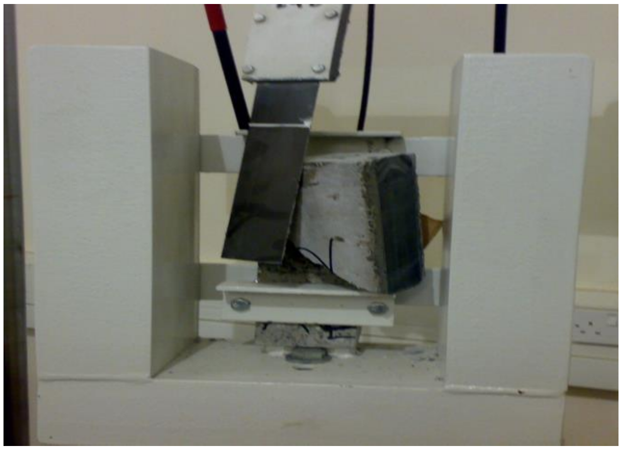
Specimen	A2
Exposure Type	Lab
Load	5 kN
Max. Load	17051.6 N
Failure displacement	14.2 mm
Bond Stress	2.27 MPa
Failure Mode	Mode 2 Concrete

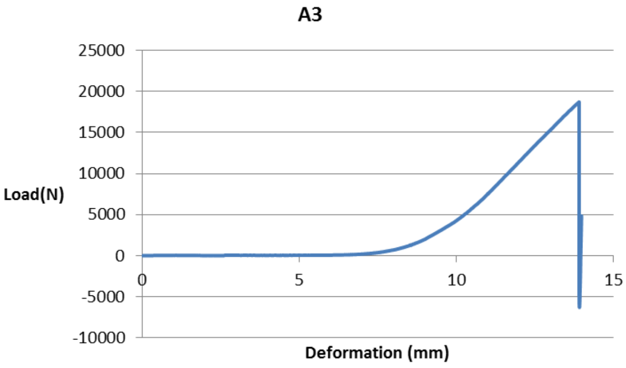




Test 3

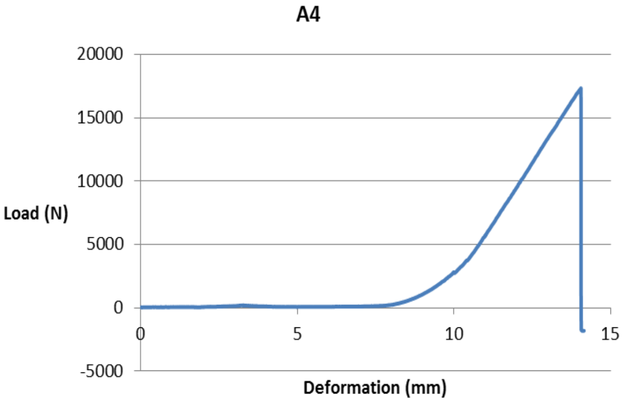
Specimen	A3
Exposure Type	Lab
Load	5 kN
Max. Load	18704.6 N
Failure displacement	13.9 mm
Bond Stress	2.49 MPa
Failure Mode	Mode 2 Concrete





Test 4

Specimen	A4
Exposure Type	Lab
Load	10 kN
Max. Load	17324.6 N
Failure displacement	14.1 mm
Bond Stress	2.31 MPa
Failure Mode	Mode 2 Concrete



5. RESULTS AND CONCLUSIONS

It has been shown that three specimens out of 12 specimens failed under sustained load. Two of them were exposed to splash zone and the other one was open dry exposed. We may conclude that as the harsher the environment, the more the resulting bond deterioration. Splash zone is a very severe environment that contains deicing salts, wet and dry cycles, sun exposure, and humidity, which should verify our results. Lab control frame did not experience any preloading failure. Therefore, we will use these specimens as a reference for the bond deterioration upon different environmental exposures. The sustained load of the preloaded failed specimens was 10 kN for open dry one, and for the splash zone: 5 kN and 10 kN respectively. We could say that the higher sustained loaded specimens, for a specific one exposure type, have more chance of failure, which will be also verified in the case of loading failure. In all three cases, the failure was in the epoxy area, not in concrete as in the loaded specimens as will be shown in the next section. Failure in the epoxy resin, which is related to our main research area, before loading might be considered as our major finding since it is relatively dangerous to have a failure at this stage. The specimens faced real harsh environment during summer time in UAE with extremely high temperatures and humidity. Moreover, CFRP sheet is a black ‘polymerized’ material, which will add more to the severity of the environment. Therefore, having this number of failed specimens during exposure requires further testing and analysis.

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