ENVIRONMENT-ASSISTED SUBCRITICAL DEBONDING OF EPOXY-CONCRETE INTERFACE

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Introduction

A large body of testing results show that debond along the FRP-to-concrete interface is one of the most common failure modes of the FRP-strengthened concrete structures. A number of critical questions regarding the long-term durability of the FRP-to-concrete interface still remain unaddressed. The behavior of the FRP-to-concrete interface in aggressive environments is mainly examined through experimental studies. An inherent problem of all existing studies is that only the loads occurred at the time of catastrophic failure are measured. However, debond is, as pointed out by RILEM [1], "a gradual process where slow growth of cracks occurs at the interface". The most distinct feature of these slow cracks is that they grow with a very slow rate at an energy release rate G only a fraction of the critical energy release rate G_c if reactive environmental species exist. This slow crack growth is a long-term process of synergistic action of environments and mechanical loads. The catastrophic interface debond (critical crack) is only the ending point of this process. For any structure which requires long-term stability, a resistance to this slow crack growth would be needed. To understand the degradation mechanism of the interface and gain the ability to accurately predict the long-term durability ultimately requires quantifying and appropriate analysis of the slow debond growth process. The current FRP research community seems unaware of the significant role of this slow debond growth, which could be a dominant mechanism for the failure of the FRP-to-concrete interface in service loads and aggressive environments. No study on it has ever been conducted or reported.

To address this research gap in long-term durability of the FRP-to-concrete interface and overcome the drawbacks in existing approach, this project proposes a systematical study on the environment-assisted debond growth along the FPR-to-concrete interface under service loads.

Wedge-driven testing:

Wedge-driven testing specimens shown in Fig. 1 were manufactured through bonding CFRP strips (Aslan 400 CFRP Laminates with dimension of 0.05 × 2 × 8 in.) to concrete blocks (2 × 2 × 8 in.) with compressive strength of 3000 psi. The mean tensile strength and modulus of elasticity of the CFRP are 350 *ksi* and 1.9 × 10^7 *psi*, respectively. Tyfo TC is used as adhesive as recommended by the manufacture. After cured for seven days at room temperature, the compressive, tensile strength and tensile modulus of Tyfo TC are 4088 *psi*, 3285 *psi* and 174,000 *psi*, respectively. Before bonding, the concrete surface was sand blasted to expose the coarse aggregates slightly. The thickness of the adhesive layer is 1 mm. To ensure the maximum adhesive strength is achieved, the plated concrete specimens were cured for 7 days before testing.

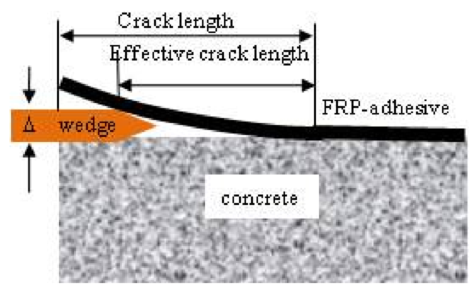

Fig. 1 Wedge-driven specimen

Testing set-up is shown in Fig. 2. The specimen was first fixed in a home-made fixture. A steel wedge with a thickness of 1/8 in. was then inserted into a pre-crack between the epoxy and the concrete of the specimen. A MTS 810 material testing system was used to slowly drive the wedge into the crack at a very low speed. A digital camera was used to take pictures of the crack tip every 10 seconds, which were then used to determine the crack length. A transparent glass vessel was used to enclose the whole specimen and the load fixture. After filling this vessel with water or other aggressive chemical solutions, the whole specimen was submerged in these fluids. In this way, we were able to apply both the mechanical forces and the environmental loading simultaneously to the specimen. Compared with the FRP-epoxy layer, the concrete substrate is much stiffer. Therefore, the concrete block can be modeled as a rigid body. Then the energy release rate at the crack tip in Fig. 1 can be calculated as:

$$G = \frac{9D\Delta^2}{2a^4} \tag{1}$$

where D is the bending stiffness of the FRP-epoxy composite beam; a is the effective crack length shown in Fig. 1; and Δ is the thickness of the wedge.

Testing Results

Subcritical debonding tests were conducted in ambient environment, in tap water, in deicing salt solutions, and in alkaline solutions. Three specimens were tested for each environmental exposure. When tested in aqueous conditions, the specimen was conditioned in the solutions for 24 hours before applying mechanical loading to ensure the crack tip is saturated with the fluids. Saturated calcium chlorides solution is used to simulate the maximum deleterious effect of the de-icing salt on the FRP-concrete interface. The FRP-to-concrete interface can also be deteriorated by naturally occurred alkaline solution due to the presence of concrete pore water. This solution has high PH value (as high as 13.5), which can attack the adhesive. To evaluate their effects on the durability of the epoxy-concrete interface, the subcritical debonding tests were conducted in the sodium-hydroxide solutions with PH = 13. All tests conducted in this study were carried out at a nominal room temperature of 21ºC.

Fig. 2 compares the subcritical debonding of the epoxy-concrete interface in ambient environment and in aqueous conditions for all specimens tested in this study. It can be seen that subcritical crack can occur in aqueous environment under much lower energy release rate. Under the same energy release rate, the subcritical crack growth in aqueous environments is much faster than that in ambient environment. This difference is induced by the existence of water and aggressive ions, which can displace epoxy from the concrete. In the aqueous environment, much more environmental species are available at the crack tip than in the ambient environment. As a result, more epoxy chains can be displaced by water molecules, leading to much fast subcritical debonding growth in the aqueous environment.

Different failure mode was also observed under the subcritical crack growth. The interface debonding changes from the cohesive failure within the concrete in critical cracking to the adhesive failure along the epoxy-concrete interface in the subcritical cracking.

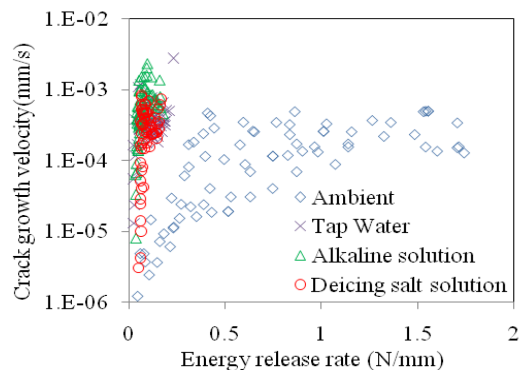

Fig. 2 Subcritical debonding of epoxy-concrete interface in different environments

Conclusions

In this study, the subcritical crack growth along the epoxy-concrete interface was observed for the first time. It was found that water can substantially reduce the energy release rate at the crack tip needed to drive the subcritical crack growth along the epoxy-concrete interface. Environment-assisted subcritical debonding testing provides a better approach to characterizing the long-term durability of the FRP-to-concrete interface in comparison with the existing critical debonding-based method.

Acknowledgements

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References

[1] Technical Committee FRP, 2003. FRP-concrete bond in structural strengthening and rehabilitation. RILEM.