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Review

Interaction of environmental factors on fiber-reinforced polymer composites and their inspection and maintenance: A review

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HIGHLIGHTS

- The long-term durability of FRP is comprehensively documented.
- The review article summarizes much of the currently published research on the durability of FRP composites.
- The review article discusses combined effects of such environmental factors.
- As well, the review article discusses the current trends in inspection and maintenance.

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ABSTRACT

Fiber-reinforced polymers (FRPs) are becoming a common method for repair and rehabilitation of civil engineering structures. FRP composites are common because they are applied to the outer surface of the structure and therefore are easy to apply and cause little disturbance during the repair. FRP may prove to be inexpensive and durable. However the long-term durability of FRP is not comprehensively documented. This article summarizes and discusses much of the currently published research on the durability of FRP composites, with an emphasis on the interaction of environmental factors and current trends in inspections and maintenance.

Contents

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1. Introduction

Fiber-reinforced polymer (FRP) composites are being increasingly used as a rehabilitation option. However, many engineers and researchers from around the United States and throughout the international community have identified certain conditions that may prove damaging to installed wraps. These include moisture, acidity, alkalinity, thermal effects, salts, freezing/thawing, pH, creep, fatigue, ultraviolet radiation, galvanic corrosion, humidity, fire, and underwater [8]. The mechanical failure mechanisms associated with these condition were described by Oehlers [25] for FRPs externally attached to concrete beams or slabs: (1) Flexural peeling cracks which always initiate at the end of the plate, and grow towards the center until debonding occurs. These cracks form because the plate is trying to stay straight while the member bends (Fig. 1); (2) Diagonal shear cracks that form prior to the onset of shear peeling. These cracks start at the base of a diagonal crack (Fig. 2); (3) Axial peeling that presents as debonding cracks and travel away from a flexural crack (Fig. 3).

The health of the matrix is very important for proper mechanical performance of a composite. When the matrix is degraded, the composite can no longer fully transfer stresses from the substrate to the fibers or from the fibers to each other. Matrices most often crack along the interface between layers rather than perpendicular to the layers. Also, it is easier for matrices to crack transversely because the composites transverse tensile strength is much lower than its longitudinal tensile strength.

The use of FRP is a relatively recent application for civil rehabilitation. Because of this, there is yet no comprehensive guide for the inspection and maintenance of FRP composites, and therefore there is a need for a set of guidelines on how to inspect and maintain previously-installed FRP composites and future installations. Such guidelines need to address things like identifying signs of wear and deterioration, judging structural integrity, how to protect installations from sources of damage, how to repair damaged wraps, and how to replace sections with irreparable or cost-prohibitive damage.

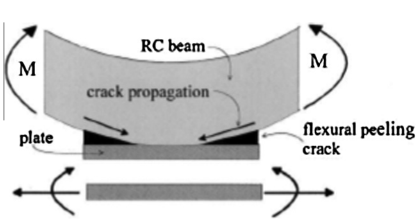

Fig. 1. Flexural peeling [25].

The objective of this work is to review previous research, guidelines, and procedures for the inspection and maintenance of FRP composites. Such a review and organization is targeted to provide a guide for the U.S. Departments of Transportation and other countries' transportation-related agencies. This review study attempts to answer the following questions. What factors contribute most to the deterioration of FRP composites? What are some warning signs of said deterioration? What methods can be used in order to get the most life out of them?

2. Combined effects

The listed exposure conditions in the introduction do not necessarily work independently of one another. Several of these conditions can occur simultaneously in the field, and, often, they exacerbate each other's damage. For this reason, many studies have sought to examine the effects of multiple exposure conditions on FRP samples, both in the lab and in the field.

A few papers offer general reviews of academic work on FRP. Weitsman [38] noted that carbon fibers themselves are effectively immune to water, acids, and alkaline solutions, although pre-stressed composites are more susceptible to solvent-related degradation. Water and saltwater have been shown to be more damaging to FRP strength than fuels or motor oil, and temperature influences moisture related damage [38]. Salt can also exacerbate freezing/thawing damage as the salt collects, expands, and contracts [10]. Additionally, creep in polymeric resins and composites has been observed to increase upon exposure to moisture [37]. Composites with unidirectional fibers exhibit this increased creep under shear loads (loading perpendicular to the direction of the fibers). Other authors have also noticed that both moisture and increased temperatures increase vulnerability to creep [10].

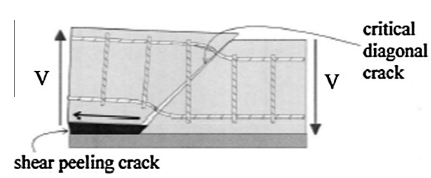

Fig. 2. Shear peeling [25].

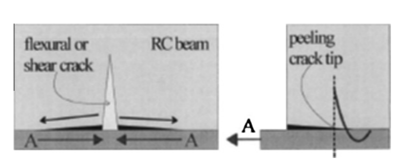

Fig. 3. Axial peeling [25].