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Fiber Reinforced Polymer Composites for Concrete Bridge Deck Reinforcement

This digest summarizes the findings from the final report on NCHRP Project 10-55, "Fiber Reinforced Polymer Composites for Concrete Bridge Deck Reinforcement," conducted by Florida Atlantic University. It was prepared by Dr. Amir N. Hanna, Senior Program Officer, from the contractor's final report authored by Dr. M. Arockiasamy, Dr. H. GangaRao, Dr. P. V. Vijay, Dr. B. Benmokrane, and Dr. M. Shahawy. Dr. Arockiasamy served as principal investigator.

INTRODUCTION

This digest describes the material requirements for fiber reinforced polymer (FRP) composites used as internal reinforcement for concrete bridge decks and presents test procedures for evaluating these composites.

Corrosion-induced deterioration of reinforced concrete bridge decks is a common and costly problem in the United States. To address this problem, there have been efforts in recent years to develop and evaluate alternatives to conventional steel reinforcement, such as epoxy-coated reinforcing steel, nonmetallic reinforcement, and other materials. One of these alternatives—FRP—has been used successfully in many industrial applications and more recently has been introduced as concrete reinforcement in bridge decks and other structural elements. While the use of FRP composites as reinforcement for concrete bridge decks provides a potential for increased service life and economic and environmental benefits, current standards and test methods do not account for the properties of FRP composite reinforcement and its relationship to performance. Therefore, there was a need to identify or develop performance-related tests to characterize and evaluate FRP composites and to recommend acceptable procedures for testing and selecting FRP composite reinforcement for use in concrete bridge decks. NCHRP Project 10-55 was conducted to address this need.

The research was conducted by Florida Atlantic University. West Virginia University, the University of Sherbrooke, and SDR Engineering, Inc., served as subcontractors. Completed in May 2003, the research included a review of current practices regarding the use of FRP composites for concrete bridge deck reinforcement, performance of laboratory and analytical investigations, monitoring of in-service bridge deck installations, and identification of protocols for the evaluation of FRP composites. The research was limited to FRP rods and grids used for deck reinforcement; it did not deal with other forms of FRP composites or prestressed concrete decks. This digest provides a summary of the work performed in this research. The materials in this digest are extracted from the project's final report.

FINDINGS

The objective of the research was to identify the material requirements of FRP composites used as internal reinforcement for concrete bridge decks. To accomplish this objective, the research team identified the parameters affecting the performance of FRP composites used for bridge deck reinforcement and the test methods applicable for their evaluation, conducted laboratory and analytical investigations to evaluate applicable test methods, monitored in-service bridge deck installations,

recommended test methods for evaluating FRP composites, and developed protocols for the recommended test methods.

Parameters Affecting FRP Reinforcement

Through a review of domestic and foreign literature and contacts with transportation agencies, researchers, and FRP composites manufacturers, the research team identified FRP properties that are likely to influence the performance of bridge decks. These properties were categorized into four groups according to their influence on FRP performance: (a) short-term behavior, (b) environmental durability, (c) mechanical durability, and (d) aging.

Properties Related to Short-Term Behavior

Short-term behavior of FRP composites was found to vary significantly depending on the types for fibers and resins, fiber volume fraction, fiber orientation, manufacturing process, and production quality control process. Properties of FRP composites that influence the performance of concrete bridge decks include tensile, flexural, shear, and bond strength; length development; and pullout.

Properties Related to Environmental Durability

Properties of FRP composites change over time, and degradation accelerates under harsh conditions. Factors that affect environmental durability include freeze-thaw condition, temperature, humidity, and presence of alkaline environment.

Properties Related to Mechanical Durability

Mechanical durability of FRP composites is influenced by the long-term response of the material when subjected to loading and environmental conditions. Mechanical durability is related to creep and relaxation, fatigue response, and stress corrosion.

Properties Related to Aging

Aging refers to the change in material properties in the absence of load. For FRP composites, aging results from changes in the chemical and physical properties of polymers due to degradation of the fiber-resin interface, moisture ingress, temperature changes, and reactions with foreign materials. Aging often influences the mechanical properties of the FRP composite.

Laboratory Investigation

The laboratory investigation included short-term and long-term tests for the purpose of determining FRP properties that affect the performance of bridge decks.

Short-term tests were conducted for measuring tensile, flexural, shear, and bond properties of FRP rods or bars and thermal properties of resins and plastics. Long-term tests were conducted for measuring moisture effect, alkaline resistance, creep, relaxation, tensile fatigue, coefficient of thermal expansion, effect of ultraviolet (UV), effect of heat on fatigue properties, effect of freeze-thaw on bond strength, effect of sustained load and freeze-thaw cycles, effect of sustained tensile stress and temperature, and effect of conditioning on flexural strength properties.

Results of the short-term and long-term tests were used (1) to establish the relevance of the different tests to the performance of FRP composites when used in concrete bridge decks and (2) to recommend test methods for evaluating these composites.

Recommended Test Methods

Based on the results of the laboratory investigation, the research team recommended two sets of tests for evaluating FRP composites: a set of tests for product qualification and quality control of FRP composites proposed for general applications and a set of tests for qualification of FRP composites intended for specific applications and conditions. Protocols for the recommended tests were also developed and presented in the report.

Qualification and Quality Control Tests

Qualification tests are performed to identify FRP bars that meet minimum levels of properties. Quality control tests are performed to demonstrate that the finished FRP rods or rebars consistently meet the quality standards established for the product and, therefore, they will perform as intended for the proposed application. The following protocols were prepared for the tests recommended for qualification and quality control evaluation of FRP composites:

- Test Method for Tensile Properties of FRP Rods
- Test Method for Flexural Properties of FRP Rods
- Test Method for Shear Properties of FRP Rods
- Test Method for Bond Strength of FRP Rods by Pullout Testing
- Test Method for Thermal Properties of Resins and Plastics by Differential Scanning Calorimetry
- Test Method for Moisture Absorption of FRP Rods

Qualification Tests for Specific Applications

The following protocols were prepared for the tests recommended for qualification evaluation of FRP composites used in specific applications and conditions:

- Test Method for Alkali Resistance of FRP Rebars
- Test Method for Creep Rupture of FRP Rods
- Test Method for Long-Term Relaxation of FRP Rods

- Test Method for Tensile Fatigue of FRP Rods
- Test Method for Coefficient of Thermal Expansion of FRP Rods
- Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV- Condensation Type) for Exposure of Nonmetallic Materials
- Test Method for Tension Fatigue of FRP Rods under Thermal Conditions
- Test Method for Determining the Effect of Freeze-Thaw on Bond Strength of FRP Rod by Pullout Testing
- Test Method for Determining the Effect of Sustained Load and Freeze-Thaw Cycles on Performance of FRP Reinforced Concrete Beam

In-Service Bridge Deck Installations

As part of the research, limited data were obtained from monitoring three bridge decks built with FRP composites: the Joffre Bridge in Sherbrooke, Quebec, Canada; the Wotton Bridge in Wotton, Quebec, Canada; and the McKinleyville Bridge in Brooke County, West Virginia. The obtained data provided information on the stress levels in the FRP reinforcement, concrete deck, and steel girders and on deck deflection and cracking. These projects demonstrated the feasibility of constructing concrete bridge decks reinforced with FRP composites. However, additional data were needed to further evaluate the applicability of the recommended protocols and confirm their relevance.

Summary of Findings

Based on the work performed in this research, two sets of tests were recommended for evaluating FRP composites used as internal reinforcement of concrete bridge decks:

1. A set of six tests for product qualification and quality control of FRP composites proposed for general applications and
2. A set of nine tests for qualification of RFP composites intended for specific applications and conditions.

Protocols for the recommended tests were also developed by the research team and presented in the agency final report; they have not been approved by NCHRP or any AASHTO committee or formally accepted for the AASHTO specifications.

CONCLUSIONS

The use of FRP composites as internal reinforcement for concrete bridge decks provides a potential for increased service life and economic and environmental benefits. However, current standards and test methods do not account for the properties of FRP composite reinforcement and their relationship to performance. This research identified performance-related tests to characterize and evaluate FRP composites used for bridge deck reinforcement, recommended procedures for testing and evaluating FRP composites, and prepared protocols appropriate for consideration as AASHTO standard test methods.

FINAL REPORT

The agency's final report, titled "Fiber Reinforced Polymer Composites for Concrete Bridge Deck Reinforcement," gives a detailed account of the project, findings, and conclusions. The report, which was distributed to NCHRP sponsors (i.e., the state departments of transportation), is available for loan on request to the National Cooperative Highway Research Program, Transportation Research Board, 500 Fifth Street, N.W., Washington, DC 20001.

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