

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Long-Term Performance of Epoxy-Bonded Rebar-Couplers

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Structural Engineering

By

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PREVIEW

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PREVIEW

University of California, San Diego

2009

DEDICATION

This work is dedicated to my parents for their support and patience, and my wife for her ceaseless motivation.

PREVIEW

EPIGRAPH

There's a right tool for every job; and the right tool is Visegrips®.
Robert Brungraber, Ph.D., P.E.

Everyone believes the results of the test except the man who performed it, and no one believes the results of the model except the man who built it.

PREVIEW

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PREVIEW

LIST OF ABBREVIATIONS

ACI – American Concrete Institute

ASTM – American Society for Testing and Materials

DMA – Dynamic Mechanical Analysis

DMTA – Dynamic Mechanical Thermal Analysis

ES – Evaluation Services

FEA – Finite Element Analysis

ICBO – International Congress of Building Officials

ICC – International Code Committee

LWMS – Low-Weight Molecular Solids

PREVIEW

LIST OF SYMBOLS

A - constant
 B - constant
 b - constant
 C - concentration of sorbate per unit sorbent
 c - constant
 C_1 - constant
 C_2 - constant
 d - concrete hole diameter
 D - diffusion coefficient
 d_b - nominal anchor diameter
 D_0 - ambient temperature diffusion coefficient
 E_a - activation energy
 F - constant
 h - thickness of a theoretically infinite sorbent plate
 h_{ef} - effective embedment depth of the anchor
 h_{ef} - effective embedment depth.
 l - total embedment depth
 l_c - depth of the upper concrete breakout cone
 M_∞ - maximum moisture content at time infinity
 M_t - cumulative gravimetric weight gain due to moisture uptake
 N_T - adhesive pullout strength of a single anchor in tension
 N_τ - failure strength at the steel/adhesive surface
 $N_{\tau 0}$ - failure strength at the adhesive/concrete surface
 P - material property undergoing degradation
 P - temperature-dependent material property at temperature T
 P_0 - the material property, of interest, at initial time zero
 P_0 - material property at reference temperature T_0
 R - Universal gas constant
 T - absolute temperature
 t - time
 T_g - glass transition temperature of the material
 T_n - load capacity of a single anchor, in tension, due to adhesive failure limit
 T_S - and arbitrary reference temperature
 y - displacement
 α_T - ratio of a mechanical relaxation time at temperature T to its value at a reference temperature T_0
 ε - strain
 λ' - elastic parameter combining material moduli and dimensional approximations
 μ_{max} - maximum adhesive shear stress at the base of the upper concrete breakout cone
 σ_E - engineering stress
 σ_T - true stress
 τ - average adhesive shear stress
 τ' - shear strength at the steel/adhesive interface

τ'_0 - shear strength at the adhesive/concrete interface
 Φ - statistical reduction factor,

PREVIEW

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PREVIEW

THE ABSTRACT OF THE DISSERTATION

Long-Term Performance of Epoxy-Bonded Rebar-Couplers

By

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Doctor of Philosophy in Structural Engineering

University of California, San Diego, 2009

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Rebar-couplers mechanically splice pairs of steel reinforcing bars, end-to-end; they are used regularly in reinforced concrete construction. Epoxy-bonded couplers are one available type, but have unique long-term performance considerations. The adhesive material used in these couplers is a two-part, field-mixed, ambient-cure epoxy system, originally designed for adhesive anchorage to concrete. Many of the adhesive systems used for anchorage to concrete, including the system used with adhesive-bonded couplers, are epoxy systems. The mechanical properties of these types of epoxies have been shown to degrade over time, in the presence of moisture. A variety of commercially available adhesive systems, for anchorage to concrete, were

studied to assess their relative resistance to moisture-based degradation. The material properties of two of the adhesive systems, both epoxies, and the performance of the rebar-couplers were then measured over a fourteen-and-a-half-month period of exposure to a variety of environmental conditions, including water immersion at a range of temperatures. From these results, material degradation models were used to predict the properties of the adhesive over the service life of the rebar-coupler. A Finite Element Analysis (FEA) model was developed to simulate the tensile failure of the epoxy-bonded rebar-coupler system and correlate degrading adhesive material properties to changes in the coupler system's behavior throughout its service life.

PREVIEW

1 Introduction

1.1 General Problems

Reinforced concrete is a composite material system consisting of two components: concrete, and reinforcement. The concrete component is itself a composite of Portland cement and aggregates. The Portland cement, through the process of hydration, cures and solidifies the material; the aggregates, usually a combination of sand and gravel, add strength and volume to the concrete. Reinforcement is generally in the form of deformed steel reinforcing bars (rebars). In practice, the rebars are placed and temporarily fixed into their final configuration, and then the fluid concrete is poured around them; the concrete then cures, forming the composite system. The reinforced concrete composite system is successful because the concrete takes the majority of compression forces and is easy to place and form; the rebars carry the tensile forces efficiently. However, it is often necessary to splice rebars together to allow for continuity of tensile forces from one rebar to the next. The most common method of splicing rebars together is to overlap them, creating what is called a “lap splice”. However, lap splicing is not always desirable and so a variety of mechanical rebar-couplers have been developed.

Epoxy-bonded rebar couplers are a type of mechanical rebar-coupler used in reinforced concrete construction; they use an epoxy adhesive system to transfer load between reinforcing bars. However, the introduction of the epoxy material into reinforced concrete structures adds additional long-term performance considerations. Although not all adhesives are epoxies, only epoxy has been used in bonded rebar-