*ACI Structural Journa*l, V. 98, No. 1, January-February 2001.
MS No. 00-042 received February 25, 2000, and reviewed under Institute publica-tion policies.
Pertinent discussion will be published in the November-December 2001 *ACI Structural Journal* if received by July 1, 2001.

Factors Influencing Bond Strength of Adhesive Anchors

by Ronald A. Cook and Robert C. Konz

This paper presents the results of a comprehensive test program investigating various factors with the potential to influence the bond strength of polymer-based adhesive anchors. Twenty prod-ucts from 12 manufacturers were included in the program for a total of 765 tests.

To establish a reference bond strength, baseline tests were per-formed at room temperature for anchors installed in cleaned, dry holes. Individual factors were isolated through separate test series that maintained baseline conditions, except for the one variable under consideration. The variables investigated included those that could be anticipated to occur during and after installation. Factors occurring during installation included the condition of the drilled hole (for example, cleaned, uncleaned, damp, and wet), differences in the concrete strength, and differences in con-crete aggregate. Factors occurring after installation included a short-term adhesive curing period and loading at an elevated temperature.

This research demonstrated that reliable predictions of adhesive anchor performance are only practical by product-specific and condition-specific testing.

Keywords: adhesives; anchor; fastener.

INTRODUCTION

Adhesive-bonded anchors are increasingly used as struc-tural fasteners for connections to hardened concrete. Be-cause of their reliance on chemical and mechanical bond, adhesive anchors are uniquely susceptible to a number of po-tentially adverse factors. Conditions that cause these factors can occur during installation and throughout the service life of the anchor.

This paper presents the results of comparative testing of adhesive anchor systems that incorporate two-part thermo-setting polymers. Most of the adhesives in this program are

commercially available products, and a few were prototype formulations. With one exception, all products were packaged and installed so that both components were automatically pro-portioned and mixed. The exception was packaged in sepa-rate, premeasured containers and required manual mixing.

Currently available commercial products are generally among several types of thermosetting plastics, including epoxies, polyes-ters, and vinylesters. A few hybrids exist that combine both or-ganic and inorganic binding agents. Similarities in chemical composition may exist among individual products, but their responses to various factors can vary widely. Some general trends seem apparent, but significant variations within and between products leave little confidence in predictions based simply on the chemical grouping.

Because no design standard currently exists in the U.S., designers must rely on information provided by the manu-facturers. The objective of this research was to provide a ba-sis for product approval testing to support design procedures that can be incorporated into ACI 318.[1] To accomplish this objective, several factors were modeled in the laboratory to determine the extent to which these factors influence the bond strength of the adhesive.

BACKGROUND

Factors that influence the bond strength of adhesive an-chors can be classified as either internal or external. Internal factors (such as chemical formulation, manufacturing pro-cesses, and packaging) are generally beyond the control of the designer and installer. Because of the many options available in developing an adhesive product, internal factors were not investigated in this test program.

External factors are generally beyond the direct control of the manufacturer, but usually can be accommodated by the designer and controlled by the installer. Two groups of ex-ternal factors were investigated for determining relative bond strengths: installation factors and in-service factors. In-stallation factors included the condition of the drilled hole during installation (for example, cleaned, uncleaned, damp, and wet) and the strength and type of coarse aggregate of the concrete base material. In-service factors included short-term adhesive curing and loading at an elevated temperature.

The effect of in-service factors related to the type of loading (for example, static, fatigue, and impact) are reported in Col-lins et al.[2] The results of this test program indicate that the strength of adhesive anchors embedded sufficiently to pro-duce steel failure under static load is not influenced by fa-tigue and impact loadings. Additional in-service factors related to environmental exposure (for example, exposure to ultraviolet light, and wetting and drying under exposure to an acid rain environment) are reported in Higgins and Klingner.[3] The results of their research indicate that the strength of adhe-sive anchors is not affected by exposure to ultraviolet light, or wetting and drying in an acid rain environment.

The bond strengths presented in this paper assume a uni-form stress distribution over the surface area between the an-chor rod and the adhesive just prior to physical failure. Studies by Cook et al.[4] show that a uniform stress distribu-tion is the most appropriate of several models presented, when compared with a worldwide test database. Studies by McVay, Cook, and Krishnamurthy [5] also show that a uniform distribution is appropriate for strength design models based on nonlinear finite element studies.

RESEARCH SIGNIFICANCE

This paper presents test results and comparative analyses for 20 different products from 12 manufacturers for a total of 765 tests. The trends observed from these results help to pro-vide the designer with a better understanding of the types of