

# Durability of an Ultrahigh-Performance Concrete

Benjamin Graybeal<sup>1</sup> and Jussara Tanesi<sup>2</sup>

**Abstract:** Significant recent advancements in cement-based, fiber-reinforced composite materials have stretched the bounds of concrete into the realm of ultrahigh-performance concrete (UHPC). The durability of a commercially available UHPC was independently evaluated through six standardized durability tests and the results are reported herein. Regardless of the curing treatment applied, this concrete exhibits significantly enhanced durability properties as compared to normal and high performance concretes. The concrete exhibited minimal damage after being subjected to two times the normal number of ASTM C 666 freeze-thaw cycles. It was innocuous to ASTM C 1260 ASR deterioration, to ASTM C 672 scaling deterioration, and to AASHTO T259 chloride penetration. The ASTM C 1202 Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration test result was negligible if any steam-based curing treatment was applied, and was very low otherwise. Steam-based curing treatments significantly enhanced the ASTM C 944 abrasion resistance. The curing treatment applied to this concrete can affect the durability properties, partly due to steam treatment increasing the degree of hydration of the concrete, improving its microstructure, and decreasing its permeability.

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## Introduction

Ultrahigh-performance concrete (UHPC) is a new class of concrete that has been developed in recent years. When compared with high performance concrete, UHPC tends to exhibit advanced mechanical and durability properties. Although there are differences among types of UHPC, there are also many overall similarities. The Association Française de Génie Civil *Interim Recommendations for Ultra High Performance Fiber-Reinforced Concretes* (2002) states that UHPC tends to have the following characteristics: Compressive strength that is greater than 150 MPa, internal fiber reinforcement to ensure nonbrittle behavior, and a high binder content with special aggregates. Further, UHPC tends to have a very low water content and can achieve adequate rheological properties through a combination of optimized granular packing and the addition of high-range water reducing admixtures.

The research presented herein was part of a larger research program aimed at fully characterizing the material behaviors of UHPC as they relate to the use of this concrete in highway bridges (Graybeal 2006). Currently, the only UHPC that is commercially available in the United States is Ductal, a product of Lafarge North America, Herndon, Virginia. This research program independently evaluated the durability of this concrete.

## Practical Applications

The durability of concrete has become increasingly important in recent years, as there has been a push to extend the life expectancy of existing and planned infrastructure. Many of the enhancements that have been found to modify the behavior of concrete on the material level have been incorporated into the next generation of concrete, UHPC. Although much of the focus on this type of concrete has centered on the mechanical and/or structural behaviors, in both the near and far terms the durability behaviors are inexorably intertwined with the mechanical behaviors. In order to make efficient use of this new generation of concrete, components and structures will have to be optimized to fully utilize the mechanical and durability properties without any unnecessary waste of material.

Although there are currently a limited number of suppliers of UHPC in the United States, it is anticipated that as the relevant applications increase, the number of commercial suppliers will increase as well. The research on this concrete to date has largely been closely associated with suppliers or potential suppliers of UHPC. The present study represents an independent evaluation of the durability of this type of concrete with a focus toward commonly implemented testing techniques. As such, the results of this study will provide valuable information by which to compare other highly durable cementitious materials.

## UHPC Constituents, Casting, and Curing

The UHPC studied in the research is composed primarily of a combination of fine powders and is internally reinforced by steel fibers. A typical composition for this UHPC is provided in Table 1. Fine sand, generally between 150 and 600  $\mu\text{m}$ , is dimensionally the largest granular material. The next largest particle is cement with an average diameter of approximately 15  $\mu\text{m}$ . Of similar size is the ground quartz with an average diameter of 10  $\mu\text{m}$ . The smallest particle, the silica fume, has a diameter

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# Performance Criteria For Concrete Durability

**Jan P. Skalny, Sidney Mindess, Andrew  
J. Boyd**



## **Performance Criteria For Concrete Durability:**

Performance Criteria for Concrete Durability H. Hilsdorf, J. Kropp, 2004-06-02 This is a state of the art report prepared by RILEM Technical Committee 116 PCD and is an authoritative international review of the subject and is an essential reference source for engineers and technologists Performance Criteria for Concrete Durability explains key aspects of concrete durability and the relationships between transport mechanisms and concrete durability characteristics It reviews test methods for measuring permeability in the laboratory and on site and discusses the many factors which influence the durability of concrete to carbonation chlorides abrasion etc

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**Concrete Durability** David Wai Sum Ho, H. T. Cao, Commonwealth Scientific and Industrial Research Organization (Australia). Division of Building, Construction and Engineering, 1993

**Performance-Based Specifications and Control of Concrete Durability** Hans Beushausen, Luis Fernandez Luco, 2015-09-24 This work gives an overview of significant research from recent years concerning performance based design and quality control for concrete durability and its implementation In engineering practice performance approaches are often still used in combination with prescriptive requirements This is largely because for most durability test methods sufficient practical experience still has to be gained before engineers and owners are prepared to fully rely on them This book compiled by RILEM TC 230 PSC is intended to assist efforts to successfully build the foundation for the full implementation of performance based approaches through the exchange of relevant knowledge and experience between researchers and practitioners worldwide

*The Quest for Absolute Concrete Durability Performance Criteria*, 2016 **Transport Characteristics of Fluid and Ions in Concrete** Nasir Shafiq, 1999 **Durability of Concrete**, 2000 Durability of Concrete V. M. Malhotra, 1994 **Concrete Durability** John M. Scanlon, 1987 *Concrete Technology* Jan P. Skalny, Sidney Mindess, Andrew J. Boyd, 2005-02-28 This edition contains 17 papers presented at past Anna Maria Workshops Topics include The Future of the Cement and Concrete Industries Testing and Standards for Concrete Durability and Designing Concrete for Durability

**CEB-FIP Model Code 1990** Comité euro-international du béton, 1993 This design code for concrete structures is the result of a complete revision to the former Model Code 1978 which was produced jointly by CEB and FIP The 1978 Model Code has had a considerable impact on the national design codes in many countries In particular it has been used extensively for the harmonisation of national design codes and as basic reference for Eurocode 2 The 1990 Model Code provides comprehensive guidance to the scientific and technical developments that have occurred over the past decade in the safety analysis and design of concrete structures It has already influenced the codification work that is

being carried out both nationally and internationally and will continue so to do

**High-performance Concrete** V. M. Malhotra,1994

Nondestructive Evaluation of Highways, Utilities, and Pipelines IV A. E. Aktan,Stephen R. Gosselin,2000

Improvement of Concrete Durability Association of Municipal Engineers,1986

Evaluation of High Absorptive Materials to Improve Internal Curing of Low Permeability Concrete Norbert J. Delatte,2007

Early age cracking of bridge decks is a national problem and may substantially reduce service lives and increase maintenance costs Cracking occurs when the tensile stress exceeds the tensile strength of the concrete This is a time dependent phenomenon since both the stress and strength change at early ages Moisture loss increases stress with increasing shrinkage and impairs strength gain Internal curing is one method that has been suggested to reduce early age bridge deck cracking particularly of concretes with low water to cementitious materials w/cm ratios Many state highway agencies have implemented high performance concrete HPC for bridge decks The low permeability of HPC is used to protect reinforcing steel and prevent corrosion However if the concrete cracks then the protection may be greatly diminished Transverse cracks due to concrete shrinkage allow water and corrosive chemicals to quickly reach the reinforcing steel causing corrosion and shortening the lifespan of the bridge deck Reducing shrinkage cracking has been the focus of recent research into mitigation strategies One unintended consequence of the use of high performance concrete may be early age cracking Field studies have shown that in some cases high performance concrete bridge decks have cracked less than a year after placement The use of internal curing to reduce autogenous shrinkage was investigated in this study One method of internal curing was through the use of coarse aggregates with high absorption capacities Another method discussed is the use of a partial replacement of the fine aggregate with a structural lightweight aggregate with a very high absorption capacity Bridge deck cracking is also affected by the nominal maximum size coarse aggregate The effect on shrinkage with increasing size is discussed ODOT's District 12 located in Northeastern Ohio found in an investigation of 116 HPC bridge decks placed between 1994 and 2001 that bridges with little or no cracking used coarse aggregate with an absorption 1 % while 75 % of bridges with unacceptable cracking used coarse aggregate with absorption 1 % This report discusses the laboratory investigation of the field results to determine the better ways to prevent bridge deck cracking internal curing or paste reduction by using an aggregate blend The laboratory investigation found that the strongest effect on cracking was due to the replacement of a small maximum size coarse aggregate with an optimized coarse aggregate gradation Increasing the coarse aggregate absorption level from

**Fundamentals of High Strength High Performance Concrete** Edward G. Nawy,1996 The first book of its kind to provide in one volume a highly practical and concise guide to the subject It starts by reviewing the fundamentals of cement technology and then proceeds to deal with applications in producing high strength high performance concretes using the various means and mineral admixtures to produce such concretes

**Annual Review** Building Research Establishment,1996

Concrete Permeability and Durability Performance Roberto J. Torrent,Rui D. Neves,Kei-ichi Imamoto,2021-12-22

Durability and service life design of concrete constructions have considerable socio economic and environmental consequences in which the permeability of concrete to aggressive intruders plays a vital role Concrete Permeability and Durability Performance provides deep insight into the permeability of concrete moving from theory to practice and presents over 20 real cases such as Tokyo s Museum of Western Art Port of Miami Tunnel and Hong Kong Zhuhai Macao sea link including field tests in the Antarctic and Atacama Desert It stresses the importance of site testing for a realistic durability assessment and details the Torrent Method for non destructive measurement of air permeability It also delivers answers for some vexing questions Should the coefficient of permeability be expressed in  $m^2$  or  $m\ s$  How to get a mean pore radius of concrete from gas permeability tests Why should permeability preferably be measured on site How can service life of reinforced concrete structures be predicted by site testing of gas permeability and cover thickness Practitioners will find stimulating examples on how to predict the coming service life of new structures and the remaining life of existing structures based on site testing of air permeability and cover thickness Researchers will value theoretical principles testing methods as well as how test results reflect the influence of concrete mix composition and processing

**Seventh CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete** ,2001 Durability of Concrete Mark Alexander,Arnon Bentur,Sidney Mindess,2017-06-26 This book provides an up to date survey of durability issues with a particular focus on specification and design and how to achieve durability in actual concrete construction It is aimed at the practising engineer but is also a valuable resource for graduate level programs in universities Along with background to current philosophies it gathers together in one useful reference a summary of current knowledge on concrete durability includes information on modern concrete materials and shows how these materials can be combined to produce durable concrete The approach is consistent with the increasing focus on sustainability that is being addressed by the concrete industry with the current emphasis on design for durability

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