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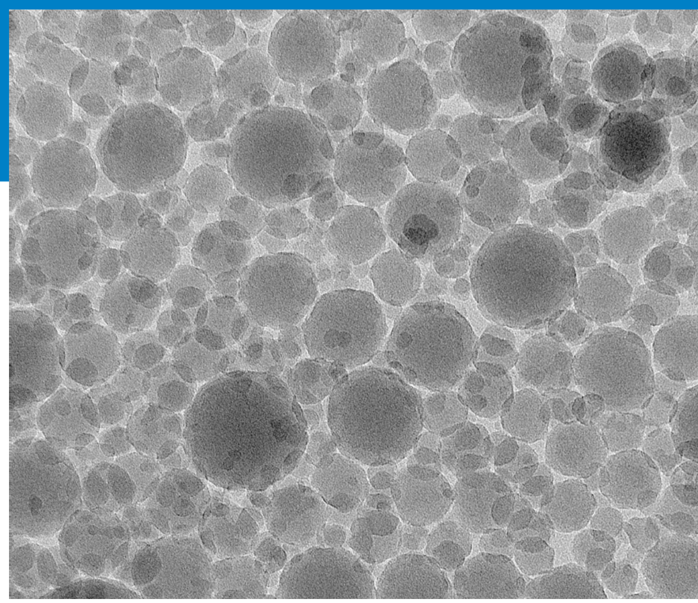

Nanotechnology for Improved Concrete Performance

SP-335

Editors:
Mahmoud Reda Taha and Mohamed T. Bassuoni

American Concrete Institute
Always advancing

Nanotechnology for Improved Concrete Performance

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PREFACE

Nanotechnology for Improved Concrete Performance

Preface: Many of the papers presented in this volume were included in the two-part session *Nanotechnology for Improved Concrete Performance*, sponsored by ACI Committee 241, Nanotechnology of Concrete at the ACI Convention in Philadelphia, PA, on October 26, 2016. In line with the practice and requirements of the American Concrete Institute, peer review, followed by appropriate response and revision by authors, has been implemented.

In the last decade, there have been considerable research efforts aimed at improving the mechanical and durability performance of concrete using nanotechnology. Exemplar work includes using nanoparticles to improve the hydration process of cement, incorporating nanomaterials to alter the mechanical and durability characteristics of concrete, and providing a new source for the self-sensing functionality of concrete. The scope of these papers encompasses experimental and applied research examining the use of nanomaterials to improve the performance of concrete at large. Readers are urged to critically evaluate the work presented herein, in light of the substantial body of knowledge and scientific literature on this topic.

We dedicate this volume of papers to the memory of Professor Robert (Bob) L. Day (1950-2014), of The University of Calgary, Canada and past Chairman of Canadian Standards Association (CSA) Committee A23.1/A23.2 (Concrete Materials and Construction), for his invaluable contributions to the field of concrete science and his remarkable mentoring of numerous concrete professionals worldwide.

The editors sincerely thank all the presenters in the 2016 session and the authors of the articles included in this special publication, as well as the reviewers for their thorough and objective assessment of the papers. Their technical contributions provide a holistic perspective of *Nanotechnology for Improved Concrete Performance*.

Mahmoud Reda Taha, Editor
Mohamed T. Bassuoni, Co-editor

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MULTI-SCALE FIBER REINFORCEMENT FOR CRACKING RESISTANCE IN CEMENT MORTARS

Joshua Hogancamp, Cesario Tavares, and Zachary Grasley

SYNOPSIS:

The current state of the art in fiber-reinforced cement-based materials indicates that adding multiple fiber types or sizes primarily creates a superpositioned behavior state: the behavior from each fiber type separately is added to the composite behavior of the material. Carbon nanofibers (CNFs) and milled carbon microfibers (MCMFs) can increase cracking resistance in cement-based materials by bridging cracks, although CNFs bridge cracks significantly smaller than cracks bridged by MCMFs. This research suggests that multi-scale fiber reinforcement (CNFs with MCMFs) might add compounded benefits to cracking resistance. Tests evaluating cracking resistance were performed utilizing a restrained-ring drying shrinkage test with Portland cement mortars. The CNFs and/or MCMFs were pre-mixed with cement using a sonication/distillation technique and/or rotary tumbling. Concentrations of CNFs and MCMFs were tested up to 5% and 6% by mass of cement, respectively. Restrained ring tests on mortar with high concentrations of CNFs or MCMFs reveal delayed cracking time by factors up to 6.4 or 2.6, respectively. Combining CNFs with MCMFs delayed cracking by a factor of at least 52. The increase in cracking resistance is attributed to the combined effects of bridging cracks of multiple sizes.

Keywords: Carbon nanofiber; carbon microfiber; mortar; cracking resistance

BIOGRAPHIES

Dr. Joshua Hogancamp graduated from Texas A&M University in 2017 with a focus in using microfine cementitious materials to enhance the efficacy of carbon nanofibers in mortars. He is currently a Post-Doctoral Appointee at Sandia National Laboratories in Albuquerque, NM.

Cesario Tavares graduated in 2014 with a Civil Engineering Master's Degree, with focus on Materials and Construction Processes, at Faculty of Engineering of University of Porto, Portugal. After three years in the construction industry as an Assistant Site Manager, he is currently a PhD candidate and Graduate Research Assistant in Texas A&M University.

Dr. Zachary Grasley received his PhD at University of Illinois at Urbana-Champaign in 2006. He is a professor, Presidential Impact Fellow, and Director of the Center for Infrastructure Renewal at Texas A&M University.

INTRODUCTION

Portland cement-based materials (PCBMs) are known for exhibiting a brittle behavior under load, with a strong resistance to compression contrasting a weak response under tension, and a tendency to crack during all ages of the material. Plastic shrinkage cracking occurs during and immediately after the initial set (period in which the matrix begins to harden); drying shrinkage cracking often occurs in the early life although it can occur at any age; load-induced cracking can occur at any age despite occurring more often during initial loading; fatigue cracking can occur after a significant period of time in the composite life; and degradation such as freeze-thaw, sulfate attack, or alkali-silica reaction can also generate cracks (1). Fibers reinforcing concrete and mortar have the ability to bridge and restrain cracks after they form, increasing ductility of the composite material and enabling it to retain some tensile capacity after cracking (2-5). The most common fiber types used in industry are macrofibers such as steel and synthetic or microfibers such as carbon or synthetic (6-8). The advent of mass-produced carbon nanofibers (CNFs) and carbon nanotubes (CNTs) has led to significant advances in nano-reinforced PCBMs including increases in flexural strength, compressive strength, plastic shrinkage cracking resistance, and Young's modulus (9-17).

The current state of the art in CNF and CNT fiber-reinforced concretes and mortars (FRCs) suggests that adding multiple fiber types or sizes results in a superpositioned behavior state, that is, the behavior from each fiber type separately is added to the composite behavior of the PCBM (18). However, research has yet resulted in a significant advance in creating compounded benefits from multiple fiber types or sizes. The objective of this research is to elucidate that using multi-scale fiber reinforcement in PCBMs can add compounded benefits to restrained ring drying cracking resistance that are greater than the sum of the benefits from either fiber alone.

THEORY

Microfibers and macrofibers are typically used in industry to bridge cracks after crack formation, and the fibers add little benefit prior to cracking. The fibers require a certain level of strain in the composite material before they become 'active' in brittle materials such as PCBMs. However, recent studies(19, 20) prove that high concentrations of CNFs in a microfine cement matrix can delay drying shrinkage cracking in restrained ring tests by bridging nearly undetectable microcracks and preventing the formation of a macrocrack. The plethora of microcracks bridged by CNFs create an 'apparent strain' as demonstrated in Figure 1. The cement paste experiences a mechanical elastic strain from the applied load, and the formation of multiple microcracks bridged by CNFs creates an additional apparent strain.