Evaluation of Self-Healing Mechanisms in Concrete with Double-Walled Sodium Silicate Microcapsules

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Abstract: The objective of this study is to evaluate a new generation of self-healing materials that hold promise for better durability and performance. The in situ polymerization method was used to develop double-walled microcapsules. The microcapsules were prepared in a single batch process containing sodium silicate as the healing agent encapsulated in double-walled polyurethane/urea-formaldehyde (PU/UF) microcapsules. Double-walled microcapsules provide enhanced durability at high temperatures compared with single-walled microcapsules while preserving adequate interfacial bonding of microcapsules. A parametric study was carried out to investigate the effect of different parameters such as agitation rate, pH, and temperature on the performance of the microcapsules and to determine the optimum microencapsulation procedure. The prepared microcapsules were then incorporated into self-healing concrete beams. To monitor the healing process of the cracks, microcracks were created by imposing a certain magnitude of displacement in the middle of the beams. The healing process of concrete specimens was monitored and quantified using portable ultrasonic nondestructive digital indicating tester (PUNDIT). Results showed that lower pH and higher agitation rate and curing temperature improve the formation of microcapsule shells. Measurements of ultrasonic wave transmission time through the concrete specimens containing different contents of microcapsules were analyzed to quantify the healing rate. It was found that the healing rate in concrete beams with 5% microcapsules was higher in the first week in comparison with specimen containing 2.5% of microcapsules. **DOI: 10.1061/(ASCE)MT.1943-5533.0001314.**

Author keywords: Self-healing concrete; Double-walled microcapsules; Ultrasonic monitoring; Concrete maintenance.

Introduction

Concrete is considered as a strong, durable, and relatively inexpensive construction material and currently is the most used construction material worldwide. However, cracks in concrete can reduce its durability. Normally, these cracks can occur at any stage of its life and most begin internally where they cannot be observed for years until major repairs are required. Therefore, inspection and maintenance techniques for concrete structures have received considerable attention. Constant inspection and maintenance of infrastructure is challenging due to the cost and the amount of labor hours required. The annual economic impact associated with maintaining, repairing, or replacing deteriorating structures is estimated at $18 to 21 billion in the United States alone (Vision 2020 2006). Concerns related to infrastructure deterioration are not limited to the economic cost of repair and rehabilitation but encompass social and environmental costs. It is obvious that repeated repairs of infrastructure over their service life are distinctly unsustainable. In such cases, automatic repair of cracks without burdensome labor and cost could be utilized to make the structure more reliable.

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Self-healing materials have the integral capability to substantially improve their mechanical properties after damage. Such recovery can occur independently and/or be triggered after an application of a specific stimulus. Therefore, these materials are projected to contribute significantly to the safety and durability of concrete structure without the high costs of active monitoring or external repair. Throughout the development of this new range of smart materials, the mimicking of biological systems has been used as a source of inspiration.

Objectives

The objective of this study is to evaluate double-walled microcapsules containing healing agent, which have enhanced durability at high temperatures compared to single-walled microcapsules. These microcapsules were prepared in a single batch process containing sodium silicate as a healing agent with polyurethane (PU)/poly (urea-formaldehyde) (UF) microcapsules (PU/UF) as the shell of the microcapsules. Different contents of microcapsules were incorporated into self-healing concrete beams. The healing process in concrete samples was monitored and quantified using a portable ultrasonic nondestructive digital indicating tester (PUNDIT) with a generator having an amplitude of 500 V and producing 54-kHz waves.

Background

A review of the literature reveals that several strategies are available to produce self-healing materials. The application of different methods such as hollow fibers (Dry 1994; Dry and McMillan 1996; Joseph et al. 2010; Li et al. 1998; Nishiwaki et al. 2006; Nji and Li 2010), microencapsulation (Boh and Sumiga 2008; Caruso et al. 2010; Gilford et al. 2014; Hemsley and Griffiths 2000; Lepech and Li 2009; Li and Nettles 2010; Li and Uppu 2010;