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Application of bio-inspired nanocomposites for enhancing impact resistance of cementitious materials

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ABSTRACT

Bio-inspired Polyvinyl Alcohol (PVA)/ Montmorillonite (MMT) nanocomposite films were synthesized and applied to High Performance Concrete (HPC) cylinders as coatings. Drop tower tests were performed to evaluate the effects of nanocomposite films on the impact response of the concrete. The preliminary results show that applying PVA/MMT nanocomposite film with 25 vol% MMT as coatings with an approximate thickness of 160 μm, demonstrated an improvement on the impact resistance of the concrete for a strain rate ($\sim 10^2$/s). For specimens subjected to the same impact energy, the damage pattern changed from complete fracture of an uncoated concrete cylinder, to only localized surface damage on the coating and the concrete cylinder substrate at the impacted region. Finite element simulations of the impact tests indicate that robust stiffness, tensile strength and toughness of the nanocomposite film, and strong bonding between the film and concrete have induced strong confinement effects to the brittle concrete cylinder substrate. This work demonstrates the potential application of bio-inspired PVA/MMT nanocomposites as protective coatings for cementitious structures.

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1. Introduction

Nacre from abalone shells possesses exceptional mechanical properties (high strength, high stiffness and high toughness) despite being constructed with weak materials, such as calcium carbonate and proteins [1]. Nacre's exquisite brick-mortar microstructure with hard and soft combinations of constituents has been a subject of extensive studies during the last few decades [1,2]. Research on synthesizing materials by adopting the brick-mortar design principles has also been conducted [3]. Notably, Launey et al. [4] used a freeze-casting approach to build nacre-like ceramic. Bonderer et al. [5] fabricated nacre-like Al_2O_3-chitosan thin film by a spin coating approach. Walter and coworkers [6] developed a paper-making approach to fabricate a multilayered PVA/MMT nanocomposite. Huang at al. [7] synthesized PVA/MMT composites by using a bottom-up assembly process called layer-by-layer (LBL) assembly. Dunkerley et al. [8] synthesized polystyrene /MMT composites with different volume fractions of MMT by using a spraying process. Recently, Wang, et al. [9] reported synthesizing bio-mimetic PVA/MMT nanocomposite with exceptional properties by using an evaporation-induced assembly method.

Bio-inspired PVA/MMT nanocomposites exhibit excellent mechanical properties, optical properties, barrier properties, and flame retardation properties [6]. In this work, bio-inspired PVA/MMT nanocomposites were synthesized by using a solution casting method. The detailed information on the synthesis methods, material characterization and properties of the nanocomposites were reported by Allison, et.al [10]. The work reported here is to evaluate the effects of applying the synthesized PVA nanocomposite film as coatings on the impact resistance of concrete by performing drop tower tests based on a ASTM Standard D4226-11 [11]. The concrete used is a type of HPC without fibers [12]. Polymer coatings such as polyurea have been applied on concrete and steel structures for mitigating blast and penetration loads [13]. E-glass/epoxy and carbon-fiber/epoxy composites have been applied on ceramic tiles for improving the ballistic performance [14]. However, few studies have been conducted to evaluate the PVA/MMT nanocomposite coating for dynamic applications.

In this work, PVA/MMT composites with 3 vol% and 25 vol% MMT were applied to the surfaces of HPC cylinders as coatings. The surfaces of the coated and uncoated HPC samples were subjected to a 1.8 kg weight striking at a speed of 1.5 m/s with a strain rate ($\sim 10^2$/s). The damage and failure of the concrete cylinders and nanocomposite coatings were examined visually, and via X-ray

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Computed Tomography (CT) scan. Finite element simulations of the drop tower tests were also performed to investigate the material responses and failure mechanisms.

2. Experimental methods and results

2.1. Sample preparation

HPC cylinders used in the experiments were fully cured at 28 days. One surface was coated with PVA/MMT nanocomposite coatings by utilizing a film-casting technique. The average size of HPC cylinder specimen was 31 mm in diameter and 14 mm in height. A modified solution intercalation method was utilized to synthesize the PVA/MMT with 3 vol% and 25 vol% MMT. The detailed information on the synthesis method was described in Allison, et al. [10]. For each of the two MMT concentrations, 5 mL of solution was prepared and cast on a single surface of a HPC cylinder by using a digital pipette. Then the samples were dried in a lab furnace at 40 °C and 10% RH. The average thickness of the coating was approximately 160 μm, as measured by a Zeiss Z1m digital stereomicroscope. Fig. 1 shows the Scanning Electron Microscopy (SEM) images of the microstructures of nanocomposite with 3 vol% MMT and 25 vol% MMT. Both nanocomposites exhibit a layered microstructure. Each layer is a composite of PVA/MMT. However, the sample with 25 vol% MMT shows a more wrinkled-like microstructure than that of 3 vol%. MMT. Fig. 2 shows the Transmission Electron Microscopy (TEM) images of nanostructures of the nanocomposites. Fig. 2a and b shows that some MMT sheets were exfoliated, but a considerable degree of agglomeration was also present in the nanocomposite with 3 vol% MMT. Fig. 2c and d shows the MMT sheets for 25 vol% MMT nanocomposite were mainly in an agglomerated state, and formed a network-like morphology.

2.2. Drop tower test setup

A BYK-Gardner Impact Tester equipped with a 1.8 kg round-shaped (12.7 mm diameter) impactor was used to perform the drop tower experiments. The impact experiments were based on a modified ASTM D-2794 standard to examine the responses of the coated and uncoated concrete cylinders. A drop height of 114 mm produced uniform through-thickness cracks in the uncoated cylinders at an energy level of 2.0 J at a strain rate (~10^2/s). This height was used as the baseline for all the samples studied. The impact tests were

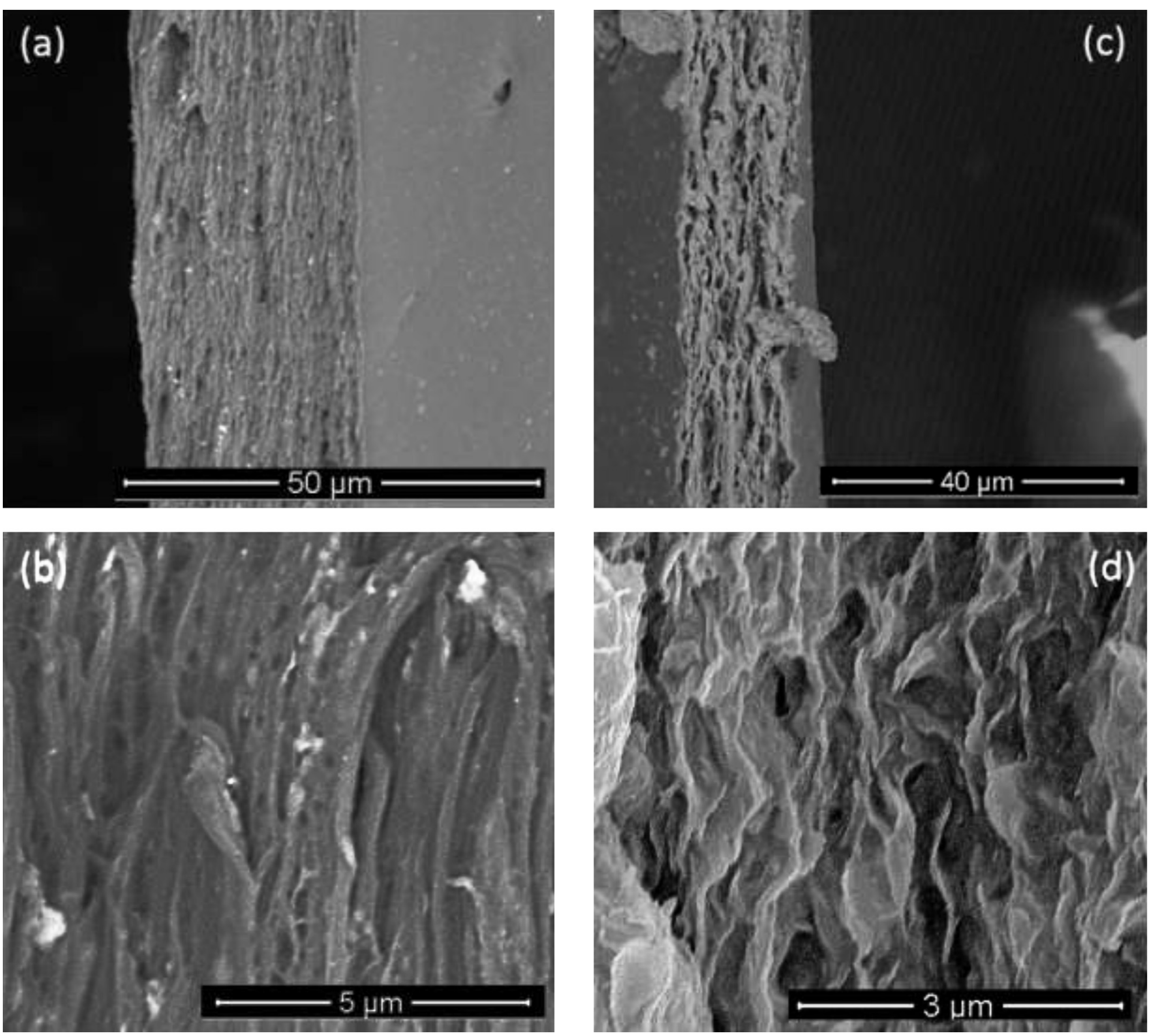

Fig. 1. Scanning Electron Microscopy (SEM) images of microstructure of 3 vol% MMT nanocomposites at a low magnification (a), and a high magnification (b). SEM images of microstructure of 25 vol% MMT nanocomposites at a low magnification(c), and at a high magnification (d).

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