Construction and Building Materials 189 (2018) 487–497

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Enhancements and mechanisms of nanoparticles on wear resistance and chloride penetration resistance of reactive powder concrete

Danna Wang [a], Wei Zhang [a], Yanfeng Ruan [a], Xun Yu [b], Baoguo Han [a,*]

[a] School of Civil Engineering, Dalian University of Technology, Dalian 116024, China
[b] Department of Mechanical Engineering, New York Institute of Technology, New York, NY 11568, USA

HIGHLIGHTS

- Nanoparticles are used to improve concrete wear and chloride penetration resistance.
- Effects of particle type and content, and curing method on properties are compared.
- Enhancing mechanisms of nanoparticles on concrete properties were investigated.
- Nanoparticles can obviously improve wear and chloride penetration resistance.

ARTICLE INFO

Article history:
Received 26 June 2018
Received in revised form 3 September 2018
Accepted 7 September 2018

Keywords:
Reactive powder concrete
Nano-SiO_2
Nano-TiO_2
Nano-ZrO_2
Wear resistance
Chloride penetration resistance

ABSTRACT

In this paper, nano-SiO_2 (NS), nano-TiO_2 (NT) and nano-ZrO_2 (NZ) at contents of 1% and 3% were adopted to improve the wear resistance and chloride penetration resistance of reactive powder concrete (RPC) with room temperature cuing or heat curing. The modification mechanisms of nanoparticles on RPC properties were investigated through X-ray powder diffraction analysis, thermogravimetric analysis, scanning electron microscopy observation and ^{29}Si Nuclear Magnetic Resonance spectra analysis. Research results show that the wear resistance and chloride penetration resistance of RPC incorporating with nanoparticles are significantly improved because the addition of NS/NT/NZ can modify the microstructures of RPC. The abrasion loss per unit area of 3 wt% NZ filled RPC with heat curing is increased by 48.46% compared with the control RPC. The chloride diffusion coefficient of RPC containing 3 wt% NT, 1 wt% and 3 wt% NZ with room temperature curing can be decreased to 0. The heat curing is more beneficial to improve the wear resistance of RPC containing NS/NT/NZ than room temperature curing, while room temperature curing is more effective to improve the chloride penetration resistance.

1. Introduction

Concrete has been widely used in the field of civil engineering because of its high mechanical strength, stability, long service life and low fabrication cost. High durability such as wear resistance, permeability and freeze-thaw resistance is required for concrete, especially for the concrete pavement. Concrete pavement is not only subjected to alternating tension and compression stresses caused by the cyclical loading of vehicle wheels, but also subjected to ion erosion in the natural environment. These will easily damage the surface of concrete and accelerate the penetration of chloride ions into concrete, thus causing corrosion of the steel reinforcement inside concrete pavement. The volume of the rusted steel bars will expand, which in turn leads to cracking and delimitation of concrete cover. The deterioration of concrete structure will cause the secondary damage. Consequently, the durability of concrete pavement is greatly reduced, and the service life is greatly shortened [1–5]. Therefore, it is very important to improve the wear resistance and chloride penetration resistance of concrete to expand its service life.

In recent years, with the fast development of nanotechnology, nanoparticles have been adopted as functional fillers to enhance the mechanical behaviors of cementitious composites. Numerous investigations have been carried out to enhance the wear resistance and chloride penetration resistance of concrete by incorporating nanoparticles. It has been confirmed that the incorporation of nano-SiO_2 (NS) and nano-TiO_2 (NT) can improve cement hydration and durability of concrete, which is mainly due to their nucleation effect and particle filling effect [6–12]. Zhang studied the wear resistance of concrete containing NS, NT and polypropylene (PP) fibers. The results indicated that the wear resistance of con-

* Corresponding author.
E-mail address: hanbaoguo@dlut.edu.cn (B. Han).

https://doi.org/10.1016/j.conbuildmat.2018.09.041
0950-0618/

Table 1
Properties of NS/NT/NZ.

Nanoparticles	Average particle size (nm)	Specific surface area (m^2/g)	Purity (%)
NS	12	200	≥99.8
NT	20	–	≥96.0
NZ	20	≥25	≥99.0

crete containing nanoparticles was significantly improved, but the enhanced extent decreased with the increase of nanoparticle content. The maximum increase in wear resistance is 180.7% for the surface index and 173.3% for the side index of concrete containing 1% NT by weight of binder [5]. Nazari et al. investigated the wear resistance of concrete containing NS and nano-Al_2O_3 cured in water and saturated limewater. They found that the wear resistance increased with the increasing content of nanoparticles with these two curing methods, and the enhancement was obvious for the concrete incorporating NS [7]. Zhang et al. studied the pore structure and chloride penetration resistance of concrete containing NT and NS. He suggested that the optimal dosage of NT was 1 wt%, which leads to a reduction of 31% in chloride diffusion coefficient. As for concrete containing 1 wt% NS, the chloride penetration resistance can be increased by 18.04%. Besides, there was a linear relationship between chloride permeability and pore structure [8]. Li observed that the chloride diffusion coefficient of 1 wt% NT filled concrete is decreased by 26% [9].

Previous studies mainly focused on the influences of nanoparticles on Ordinary Portland cement paste or concrete. However, few studies focus on reactive powder concrete (RPC) incorporating nanoparticles and their wear resistance and chloride penetration resistance. RPC has high-strength, high-tensile, high-toughness and excellent high-durability, all of which are beneficial to resist external impact and wear [13–16]. It can be expected that adding nanoparticles into RPC may greatly improve its wear resistance and chloride penetration resistance. Furthermore, the incorporation of nano-ZrO_2 (NZ) may also enhance the wear resistance and chloride penetration resistance of RPC due to its high-toughness and high-hardness [17].

Based on the above reasons, NS/NT/NZ at contents of 0, 1%, and 3% by weight of cement are added to RPC in this paper. The wear resistance and chloride penetration resistance of RPC containing different types and contents of nanoparticles with room temperature curing for 28 d and heat curing for 3 d are investigated and compared. Then the enhancement mechanisms of three kinds of nanoparticles on the two properties of RPC are also studied.

2. Materials and experimental method

2.1. Raw materials and mixture proportions

In the present study, Portland cement (P·O 42.5R) produced by Dalian Onoda Cement Co. Ltd. in China was adopted. Quartz sand (Dalian Lianxin Quartz Sand Factory, China) with a diameter range of 0.12–0.83 mm was used as fine aggregate. The incorporated NS was produced by Tokuyama in Japan. NT and NZ used as nano fil-

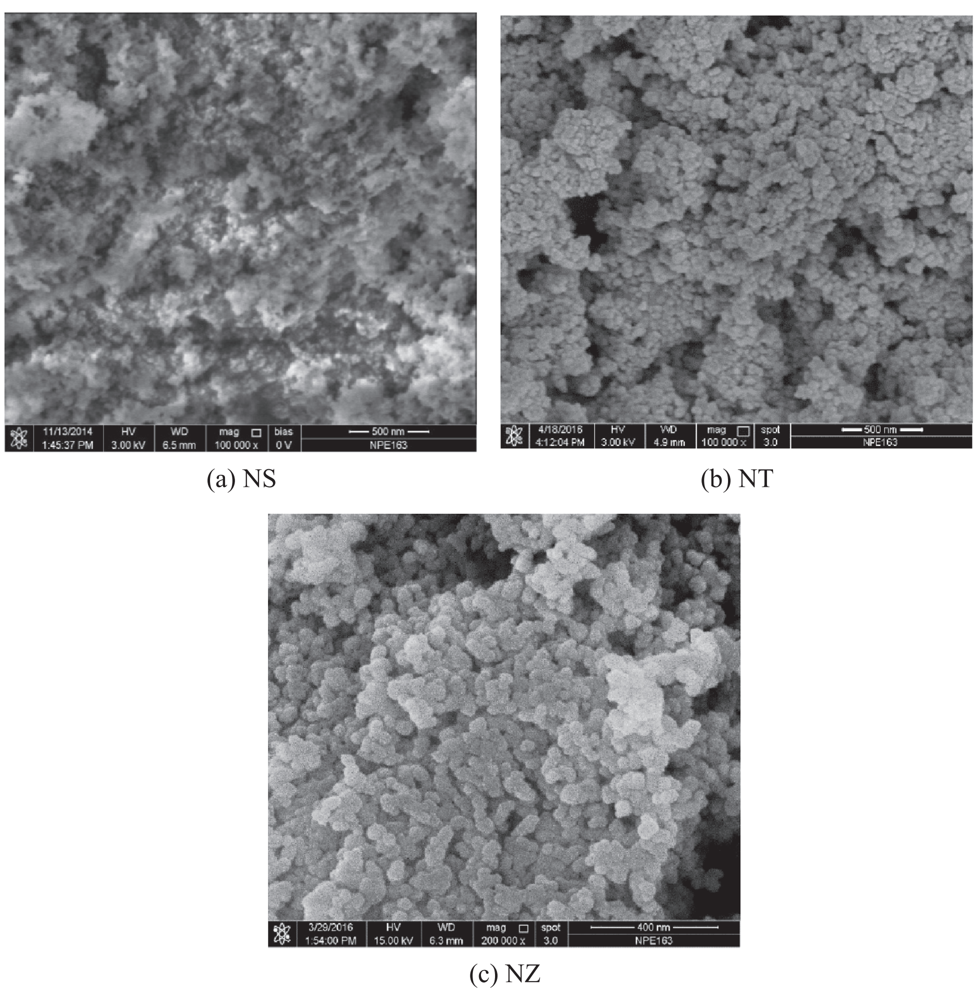

Fig. 1. SEM images of (a) NS, (b) NT and (c) NZ.