Materials and Design 112 (2016) 58–66

Contents lists available at ScienceDirect

Materials and Design

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

Effects of nanoparticle on the dynamic behaviors of recycled aggregate concrete under impact loading

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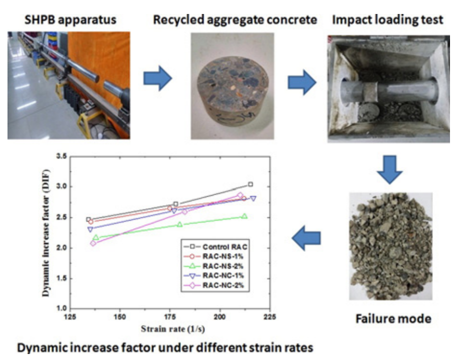
HIGHLIGHTS

- Nano-SiO_2 and nano-$CaCO_3$ modified recycled aggregate concrete (RAC) exhibit higher dynamic compressive strength compared to the control RAC.
- Nanoparticles can reduce the strain rate sensitive of cement mortar in RAC, and then decrease the dynamic increase factor.
- Compared to nano-$CaCO_3$, nano-SiO_2 more effectively improves the dynamic compressive strength of RAC, but less obviously enhances the deformation capacity.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form 12 September 2016
Accepted 13 September 2016
Available online 16 September 2016

Keywords:
Recycled aggregate concrete (RAC)
Nanoparticles
Split Hopkinson pressure bar (SHPB)
Impact loading
Dynamic increase factor (DIF)

ABSTRACT

A 100 mm-diameter split Hopkinson pressure bar (SHPB) was applied to investigate effects of nanoparticles on the dynamic mechanical properties of recycled aggregate concrete (RAC) under impact loading. The nano-SiO_2 (NS) and nano-$CaCO_3$ (NC) were incorporated to replace cement by mass of 1 and 2% in RACs. The impact velocities were set as 7.7, 9.8 and 11.6 m/s in the SHPB tests. The effects of nanoparticles on failure patterns, compressive strengths, elastic modulus, peak strain and dynamic increase factor (DIF) of RACs under different strain rates were analyzed and discussed. The results show that nanomodified RACs exhibit higher both quasi-static and dynamic compressive strengths compared to control RAC. Dynamic elastic modulus of RAC seems not be affected by nanoparticle dosages and impact velocities. Compared to NC, NS is more effective to improve dynamic compressive strengths of RAC. On the other hand, the nanoparticles modified RACs exhibit lower DIF values than that of the control RAC. Moreover, NC obviously more reduces the DIF values of nanomodified RAC than NS.

1. Introduction

Construction wastes account for a huge proportion in demolition waste. In most cases, the construction wastes have not been appropriately handled and eventually caused environmental problems. As waste concrete is a major part of the construction waste, making the waste concrete into aggregate and using it to prepare recycled aggregate concrete (RAC) may be the best way to tackle this problem. But researches have showed

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http://dx.doi.org/10.1016/j.matdes.2016.09.045
0264-1275/

that RAC is inferior to normal aggregate concrete (NAC) in several aspects such as mechanical properties and durability [1–2], which has restricted the promotion of structural application of RAC.

Due to an ultrafine size, nanoparticles including nano-SiO_2 (NS) and nano-$CaCO_3$ (NC) have unique physical and chemical properties which are different from other common materials. Nanoparticles have provided new insights on how to develop the civil engineering materials. Due to the pozzolanic reaction, nucleation and filling effect, NS can make microstructure of cement paste more compact and uniform, improve the condition of interfacial transition zone (ITZ) and enhance resistance of water penetration of concrete [3]. Studies indicated that NS can improve strength of concrete, especially the early-age strength [4–5]. But because of large specific surface area of the nanoparticles it usually demands superplasticizer to achieve the same slump as concrete without adding nanoparticles [6]. Researches on NC have shown that when the content of NC increased to a certain degree, the cement paste achieved higher strength and shorter setting time, but the flowability decreased [7]. Similar to NS, NC can accelerate the hydration process of cement, and fill up the pores of the loose net structure around cement particles, making the microstructures of hardened cement paste denser [7]. Although both the NS and NC have disadvantages in dispersion, studies reveal that there are optimum amounts for incorporating NS and NC in concrete. If the dosage exceeds the threshold amount, the improvements in mechanical performance of concrete decrease [8–9].

Based on the investigation of cement paste and normal aggregate concrete (NAC), a few researchers also attempted to improve the properties of RAC by incorporating of nanoparticles. The test results revealed that some similar results were obtained as those in NAC [10–12]: nanoparticle additions can improve microstructure and enhance strength of RAC but decrease workability. Nanoparticles are more influential at early-age properties. Typically, the RAC includes old cement paste and two ITZ, which makes it inferior to NAC. But Hosseini et al. [10] and Mukharjee at al. [11,13] reported that RAC can achieve comparable compressive strength as NAC after 28 days when the content of NS reaches 3% of cement by mass.

Currently, frequent impact and explosion phenomena have caused wide public concerns for concrete structures. For instance, the Tianjin explosion in China 2015, which caused more than one hundred people death and over ten billion property losses. Therefore, many investigations have been carried out to explore and improve the dynamic performance of concrete materials [14–16]. Since nanomodified RAC exhibits tremendous potential in better promoting the applications of RAC, relevant studies on dynamic mechanical properties of nanoparticles modified RAC become more and more necessary. But up to now, only few studies have been conducted in relevant area. Researches for the dynamic mechanical properties of nanomodified NAC indicate that nanoparticles can greatly improve the mechanical properties of RAC under impact loading [17,18]. Therefore, experiments should be carried out to investigate effects of nanoparticles on the dynamic mechanical properties of RAC under impact loading.

In this study, nanoparticle modified RACs incorporating NS and NC were tested with a 100 mm diameter SHPB under different velocities. It aims to analyze the influence of different nanoparticles and different dosages on the dynamic mechanical properties of RAC such as compressive strength, DIF and peak strain. The mechanism of nanoparticles affecting dynamic performances of RAC under high strain rate is discussed correspondingly. The related conclusions will provide an insight into promoting the structural application of RAC in the field practices.

2. Experimental programs

2.1. Raw materials

Ordinary Portland cement of grade 42.5, river sand as fine aggregates and tap water were used in sample preparation. The recycled coarse aggregates (RCA) were obtained from a local RCA manufacturing plant in Shanghai, China. Natural coarse aggregates (NCA) were gravels from a local aggregate production plant. Physical properties of the coarse aggregates are shown in Table 1. The physical properties of NS and NC are summarized in Table 2. Naphthalene superplasticizer was added with 0.75% of cement by mass to improve flowability and acts as dispersant to achieve uniform dispersion of the nanoparticles.

2.2. Specimen preparation

The polyvinylchloride (PVC) pipelines with an inner diameter of 94 mm were cut into short pipelines with a height of 500 mm to act as moulds for RAC specimen casting. A small piece of wood was stuck to the bottom end of the pipeline to prevent leakage of slurry. Since the RCA has bigger water absorption compared to the NCA [19], some additional water was added for make sure that the RAC and NAC can achieve the same effective water to cement ratio. In this test, the additional water was calculated for RAC by the water absorption of RCA under saturated surface dry (SSD) condition. Five groups of RAC specimens were cast to compare the dynamic properties of RAC and nanoparticles modified RAC under impact loading. The dosages of nanoparticles (NS and NC) were 1 and 2% by weight of cement, respectively. The related details about the mixing proportion of RACs are given in Table 3.

Due to the strong van der Waal attractive forces, NS and NC tend to agglomerate in the RAc, which may have adverse consequences on the effect of nanoparticles on RAC. So the naphthalene superplasticizer was first mixed with water, then nanoparticles were incorporated into the mixed solution and quickly stirred for 1 min to make the nanoparticles dispersed uniformly. The raw materials including cement, coarse aggregates and fine aggregates were poured into the concrete mixer and stirred for another 2 min. Then nanoparticle solution was poured into the mixer and stirred for another 2 min. After proper mixing, the fresh RAC was poured into the PVC pipelines and vibrated for 30 s. The RAC specimens were cured under standard condition at 20 ± 2 °C and relative humidity of 90 ± 5%. Then RAC specimens were cut into cylinders with diameter of 94 mm and length of 47 mm for both the quasi-static and SHPB tests. The top and bottom ends of the specimens were ground by a grinding machine to make them parallel to each other. The quasi-static and SHPB tests on RACs were conducted at 28 days curing after RAC specimens were casted.

2.3. Testing methods

The dynamic properties of nanoparticles modified RACs specimens under impact loading were conducted using a 100-mm-diameter variable cross-sectional SHPB apparatus at the Center for Integrated Protection Research of Engineering Structures in Hunan University, China, as

Table 1
Physical property of natural and recycled coarse aggregates.

Type	Grading (mm)	Bulk density (kg/m^3)	Apparent density (kg/m^3)	Water absorption (%)
NCA	5 ~ 20	1420	2752	0.67
RCA	5 ~ 20	1235	2637	8.54

Table 2
Physical properties of nano-SiO_2 (NS) and nano-$CaCO_3$ (NC).

Type	Appearance	Solids content (%)	Purity (%)	Diameter (nm)	PH value
Nano-SiO_2	Transparent liquid	30	99.5	15 ± 5	9 ~ 11
Nano-$CaCO_3$	White powder	–	98.5	15 ~ 40	8 ~ 9