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Effect of limestone powder in manufactured sand on the hydration products and microstructure of recycled aggregate concrete

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HIGHLIGHTS

- Only a small quantity of limestone power (LP) reacts during hydration.
- LP improves the compactness of the cement matrix and the ITZ.
- LP does not change the composition of hydration products but varied its morphology.
- LP sets seeds for nucleating new hydration products and accelerates the hydration.

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ABSTRACT

In this paper, X ray diffraction test and Scanning electron microscope test were designed to investigate the effect of limestone powder (LP) in manufactured sand on the hydration products and microstructure of full recycled coarse aggregate concrete samples. The results showed that most of LP was inactive, except only a small quantity of LP participated in the hydrating reaction at mid-late period. This small amount of LP did not change the composition of hydration products but varied their morphology. Some amount of LP filled in the pore structure of cement matrix and in the interface between recycled coarse aggregate and new harden cement paste, improving the compactness of the cement matrix and the interfacial transition zone. The nucleation around the LP who filled in the pore structures was also observed, and the hydration products gradually formed and subsided on the surface of these LP and accelerated the cement hydration.

1. Introduction

Manufactured sand (MS) is a by–product of crushing rock as natural aggregate, mixing with different levels of LP whose particle diameter is less than 75 μm during the crushing process [1–3]. Replacing river sand with MS retards the depletion of the natural fine aggregate. Properties, such as mixing proportion [4], workability [1,5], mechanical behaviors [6–8] and others [9,10], of concrete containing MS thus have been an important topic in the world-wide. It has been found that the workability and compressive strength of MS-included concrete were comparable with those of natural fine aggregate concrete [6,8]. Compared to concrete containing natural sand, a lower water-to-cement ratio and a greater amount of water-reducing agent may be needed [5,11]. It is thus feasible to produce concrete by using MS in the place of natural sand [2,3].

Considering that the stone powder in MS maybe affect the behaviors of concrete, some researchers focused on the influence of stone powder content on the properties of concrete containing MS [6,12–14]. It is found that the stone powder increased the compressive strength of concrete with a small percentages (less than10%) of powder in MS. Once the powder content exceeded 10%–20% mass percentage, the compressive strength decreased with the increase of the stone powder level.

On the other hand, recycling demolished waste concrete as coarse aggregate is also became an international consensus nowadays [15–18]. Thus, it is a breakthrough to adopt the MS and recycled coarse aggregate (RCA) simultaneously to reproduce new concrete in order to meet the sustainable development of building materials. However, it is generally considered that some drawbacks of recycled coarse aggregate, such as higher water absorption, more weakness in interfacial transition zone [19,20] would degrade the mechanical properties of concrete containing recycled

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coarse aggregates compared with conventional concrete. This paper aimed to study the mechanism of LP in MS on the hydration products and microstructures that could further affect the compressive strength of recycled aggregate concrete. X ray diffraction (XRD) and Scanning electron microscope (SEM) tests were conducted to investigate the hydration product and its microstructure morphology separately.

2. Experiments

2.1. Raw materials and mix proportions

Demolished concrete from a highway pavement was crushed and sieved as 5–31.5 mm coarse aggregate, with the physical properties listed in Table 1. The MS, bought from a local commercial plant, was adopted as fine aggregate, which contains a high level of LP due to the defect of crushing process. As LP improved the compressive strength when its mass percentage in MS was lower than 10–20% [6,12,14], here 15% mass percentage of LP was mixed in MS in this investigation. The MS was first sieved using vibration screening machine (ZBSX-92A) to achieve 0% mass percentage of LP, and then 15% mass percentage of LP was mixed in MS. The mineral components of LP was determined using XRD test before concrete casting, with result showing that $CaCO_3$, $CaMg(CO_3)_2$ and little content of α-SiO_2 were detected in these LP.

Two different mix proportions were determined in this paper corresponding to two different kinds of MS (i.e. MS with 0% and 15% content of LP), the addition water (AW) was also added in this mixture to consider the water absorption of RCA. Details were shown in Table 2. For each mix, three cubic specimens with sides of 150 mm were prepared for the compressive strength test, with test results listed in Table 2. As can be seen in Table 2, 15% mass percentage of LP in MS increased the compressive strength of concrete, a finding that agreed with the test result obtained by other researchers [6,14].

2.2. XRD and SEM tests

The experimental investigation in this paper comprised of XRD and SEM studies on the hydration product of cement paste and on the microstructures of recycled coarse aggregate concrete separately. Samples MRC-0 and MRC-15 cured for 3 days (d), 7 d, 14 d, 21 d and 28 d were pulverized and the hydration cement pastes were selected. Each cement paste was first immersed in absolute ethanol solution for 24 hrs in order to terminate the hydration reaction and then was kept in an oven for 24 hrs at 105 ± 5 °C until it reached to a constant weight. The dried cement pastes were grinded into powder and then were submitted to test the diffraction pattern using an X-ray diffractometer. The measurement conditions of XRD were a tube voltage of 30 kV and a tube current of 20 mA. Scans were repeated continuously from 5° to 80° with 0.1°/s using Cu target.

The microstructure morphology of concrete cured for 28 d was tested using SEM method. Regular pieces of 10-mm size were cut ensuring it containing recycled coarse aggregate, old harden cement paste, and new harden cement past. The samples were also immersed in absolute ethanol solution for 24 hrs to stop the hydration reaction, and then were kept in an oven for 24 hrs at 105 ± 5 °C to remove evaporable water. Finally the samples were mounted on metal stubs, and were sputter-coated before subjecting to the electron beam from HitachiS-3400W Scanning Electron Microscope.

Table 1
Physical properties of recycled coarse aggregate.

Grain size/mm	Absorption/%	Crushing index/%	Apparent density/kg/m^3
5–31.5	4.25	15	2613

3. Results and discussion

3.1. XRD patterns and hydration analysis

The XRD patterns of samples MRC-0 and MRC-15 at age of 3 d, 7 d, 14 d, 21 d, and 28 d are shown in Figs. 1 and 2. As can be seen in Figs. 1 and 2, the principal hydration products were $Ca(OH)_2$, ettringite (AFt), $Ca_4Al_2O_6{\cdot}11H_2O$ and so on, while the $C_3S_2H_8$ cannot be clearly observed because this hydrate varied over a wide range and its semi-amorphous nature. The peak of hydration products in XRD pattern characterized the content of these constituents during the chemical reaction process. As the curing period increased, the chemical cement compound gradually reacted, and hydration products be formed continuously. It can be obviously observed from Figs. 1 and 2 that the characteristic peak of Ca $(OH)_2$ was obscurely found in XRD patterns of both MRC-0 and MRC-15 samples in the early hydration period. This type of peak was clearly observed at age of 14 d, 21 d and 28 d, indicating that C_3A and C_4AF were the most reactive compounds in the early

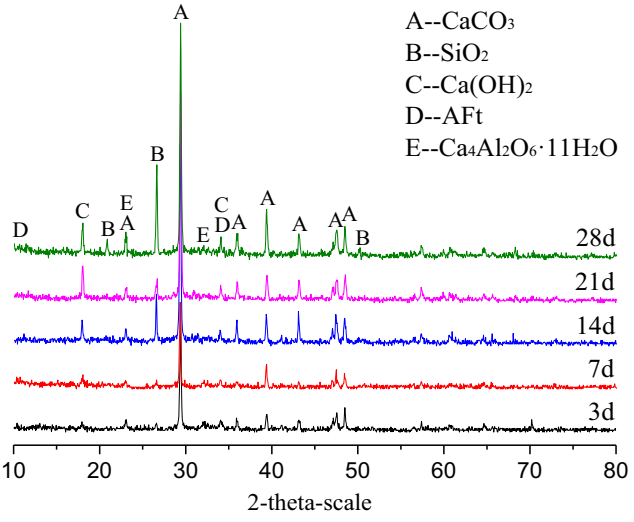

Fig. 1. The XRD pattern of MRC-0.

Table 2
Mix proportions.

Series	W/C	Content/kg/m^3						f_{cu}/MPa
		W	AW	C	MS	LP	RCA	
MRC-0	0.40	195	45	487.5	707.0	0	1060.5	44.33
MRC-15	0.40	195	45	487.5	601.0	106.0	1060.5	46.81

Note: W-water; C-cement; RCA-recycled coarse aggregate; f_{cu}-compressive strength.