

Experimental Research on the Wettability of Recycled Aggregate Concrete with Fly Ash

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Abstract: Material adsorption, the reverse process of evaporation diffusion, directly reflects the wettability of materials. Wettability is one of the main factors that affect the drying shrinkage of materials. A device that measures the wettability of recycled aggregate concrete (RAC) with fly ash is proposed in this study based on pore structure theory. The isothermal absorption curve of RAC is examined with different fly ash contents. Results show that as the recycled aggregate replacement rate increases, the moisture absorption capacity of RAC gradually increases. The addition of fly ash improves the porosity of RAC structures and reduces material wettability.

Keywords: Recycled aggregate concrete; wettability; fly ash; drying shrinkage; experimental research.

1. INTRODUCTION

Recycled aggregate concrete (RAC) refers to new concrete prepared with recycled concrete aggregate (RCA), which is made with construction waste to replace or partially replace the natural aggregate. Many experts have conducted numerous experimental studies on the drying shrinkage of concrete materials. The results of these studies show that under similar experimental conditions, RAC exhibits greater shrinkage deformation than natural aggregate concrete (NAC) [1-7]. However, RAC is rarely used because of the physical and mechanical defects of RCA. Thus, reducing RAC material shrinkage and improving the crack resistance of RAC materials have become important research topics.

Non-uniform concrete shrinkage often occurs during the initial use period and is caused mainly by moisture diffusion inside the material [8]. Therefore, studying initial moisture absorption is important for RAC drying shrinkage research. The isothermal moisture properties of the material are related to the composition and structure of the material itself. The wettability of cement-based materials is based on isothermal absorption curves. In China, Li [9] studied the expanded polystyrene board, extruded polystyrene board, and polyurethane insulation of three commonly used building insulation materials. Yang [10] investigated the building materials used in raw soil enclosure structures. However, only a small amount of data on RAC moisture absorption exists overseas. Furthermore, the test equipment for isotherm moisture

absorption and adsorption requires high precision. The test is difficult to implement because it requires much time. Therefore, a device that measures RAC moisture absorption is proposed in this study based on pore structure theory.

2. EXPERIMENTAL DESIGN

2.1. Experimental Principle

The Washburn dynamic method is the most common means of testing solid contact angles. It is expressed as Eq. (1).

$$h^2 = (\gamma R \cos \theta / 2\eta)t \quad (1)$$

where h is the height in cm of the water rise over time t ; R is the effective capillary radius in cm; γ is liquid surface tension in dyne/cm; and η is the viscosity of the liquid in Pa·s.

The h^2-t diagram approximates a linear line. Slope k is computed with Eq. (2) and is used to obtain contact angle θ in Eq. (3).

$$k = \gamma R \cos \theta / 2\eta \quad (2)$$

$$\theta = \arccos(2k\eta / \gamma R) \quad (3)$$

The increased height h of the liquid in RAC is difficult to measure accurately. Thus, the h^2-t curve tested in the experiment is replaced by the m^2-t curve according to the characteristics of the cement-based composite materials, where m is the increased weight of the liquid in RAC. A capillary bundle parallel is formed within RAC by the large number of cylindrical pores in the capillary channel beam.

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The relationship of water quality m and water rising height h is shown in Eq. (4).

$$m = \varepsilon \cdot h \cdot \rho_w \sum s_i \tag{4}$$

where m is the weight in g of the water sunk into RAC over time t ; ε is the porosity of RAC to the decimal meter; h is water rising height in cm over time t ; ρ_w is the water density; and s_i is the i th sectional area of the cylindrical capillary tube.

Therefore,

$$m^2 = (\varepsilon \cdot \rho_w \cdot \sum s_i)^2 \cdot ((\gamma R \cos \theta / 2\eta)t) \tag{5}$$

$$k = (\varepsilon \cdot \rho_w \cdot \sum s_i)^2 \cdot (\gamma R \cos \theta / 2\eta) \tag{6}$$

As shown in Eq. (5), the m^2-t curve should approximate a straight line.

Given the difficulty in determining the effective radius R of the capillary bundle, effective radius R is replaced in this study with effective radius R_m of the capillary bundle model (assuming uniform distribution and that all pores are cylindrical and continuous). Its value can be approximately expressed as Eq. (7).

$$R_m = (2\varepsilon \cdot V_{sj} / (l \cdot \pi))^{1/2} \tag{7}$$

where ε is the porosity of RAC; V_{sj} is the volume of the samples; and l is the specimen height.

Thus, Eq. (4) and (5) are transformed into Eq.(8) and (9).

$$m^2 = (\varepsilon \cdot \rho_w \cdot \sum s_i)^2 \cdot ((\gamma R_m \cos \theta / 2\eta)t) \tag{8}$$

$$k = (\varepsilon \cdot \rho_w \cdot \sum s_i)^2 \cdot (\gamma R_m \cos \theta / 2\eta) \tag{9}$$

As a result, the contact angle is

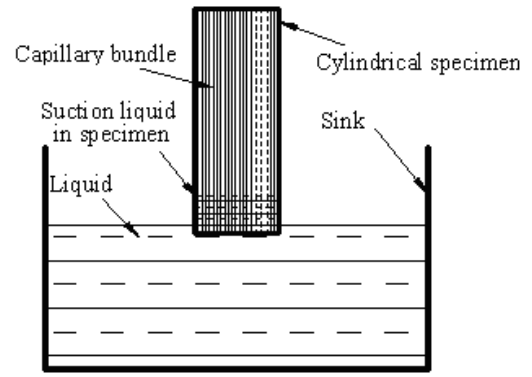


Fig. (1). Simplified diagram of the wettability testing device.

$$\theta = \arccos(2k\eta / \gamma R_m) \tag{10}$$

2.2. Experimental Materials, Equipment, and Methods

Construction waste (CW) was obtained from a building demolition in Chongqing City, China. The cement was P•S 32.5. The physical properties of the fly ash are shown in Table 1.

Fig. (1) shows the design principles of the device used to measure the contact angle of RAC. The cylindrical RAC specimen was placed inside a mold with an inner diameter of 4.5 mm and an outer diameter of 5 mm.

The mix design of RAC, which employs C30 natural mix proportion as a reference, is shown in Table 2. Each sample was loaded into the device (shown in Fig. (1)) three times, and each appropriate plug was pounded. The sample and the mold were then placed in a standard curing room for conservation. After 7 d, a drying test was performed at 80 °C [11] until the sample weight became constant. Afterward, under the conditions of 60% humidity and 20 °C ± 2 °C, the rate of water loss from the sample was tested to calculate the

Table 1. Physical Properties of the Fly Ash Used in the Experiment

Product Grade	Fineness (%)	Water Demand Ratio (%)	SO ₃ (%)	Loss on Ignition (%)
I	7.3	112	1.87	0.63

Table 2. Mix Design of RAC (kg/m³)

Project	Number	Cement	NA	RCA	Sand	Water	Sand ratio	W/C	FA
RCA replacement ratio	RC0	426	1000	0	560	200	0.36	0.47	0
	RC30	426	700	300	560	200	0.36	0.47	0
	RC70	426	300	700	560	200	0.36	0.47	0
	RC100	426	0	1000	560	200	0.36	0.47	0
Fly ash Content	FA0	426	0	1000	560	200	0.36	0.47	0
	FA10	426	0	1000	560	200	0.36	0.47	43
	FA20	426	0	1000	560	200	0.36	0.47	85
	FA30	426	0	1000	560	200	0.36	0.47	128

contact angle of RAC.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The effects of the recycled aggregate and fly ash on RAC hygroscopic capacity m^2 is shown in Figs. (2a) and (3a), respectively.

As shown in Fig. (2a), the moisture absorption capacity of RAC increases with the increase in the recycled aggregate replacement rate mainly because of the existence of numerous cracks and the porosity and age of the cement mortar in the recycled aggregate itself. Cracks, porosity, and cement mortar age cause high water absorption in the recycled aggregate, thereby increasing the moisture absorption capacity of RAC. Porosity and old cement content in RAC increase as the RCA replacement rate increases.

As shown in Fig. (3a), the moisture absorption capacity of RAC decreases with the increase in fly ash content; however, the decline is not obvious possibly because the porosity of RAC with fly ash gradually declines when the amount of fly ash is increased.

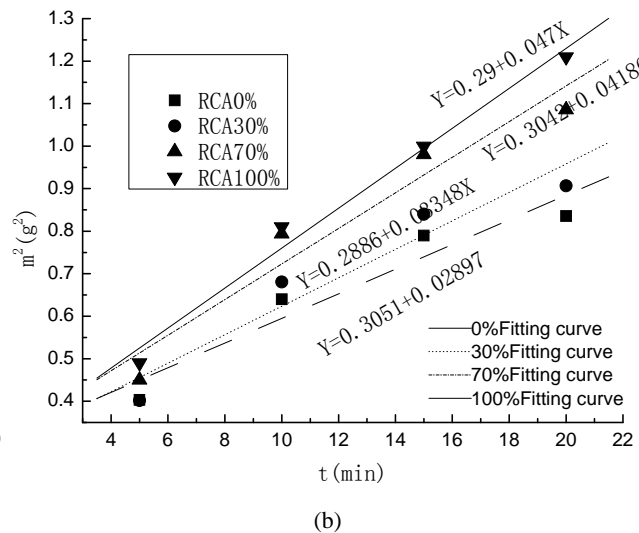
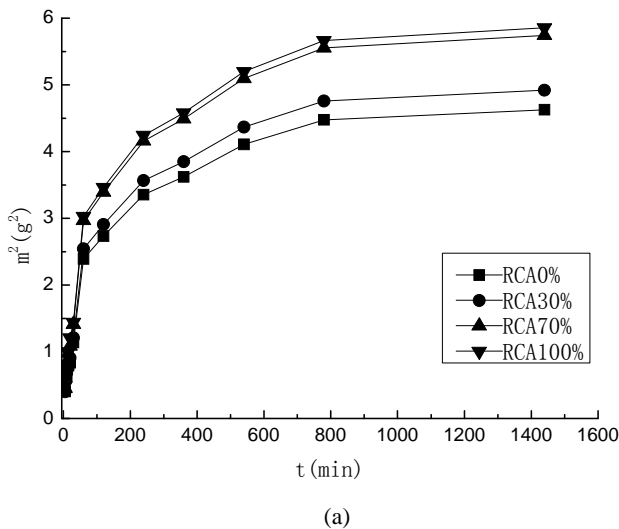


Fig. (2. a,b). Effect of the recycled aggregate on hygroscopic capacity m^2 .

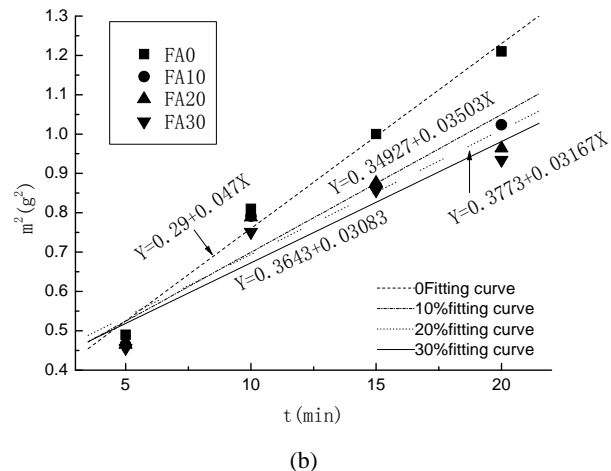
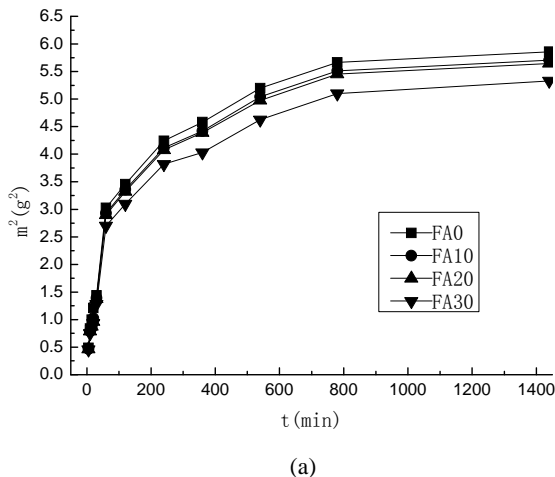


Fig. (3. a,b). Effect of fly ash content on hygroscopic capacity m^2 .

Figs. (2b) and (3b) show the linear fitting curve obtained with the m^2-t curve in the first 20 min. Slope k is obtained from this linear fitting curve. $\cos \theta$ and contact angle θ are calculated according to Eqs. (9) and (10). The calculated results are shown in Table 3.

The contact angle decreases with the increase in the recycled aggregate replacement rate as shown in Table 3. This result indicates that the wetting properties are upgraded gradually. The value of $\cos \theta$ increases with the increase in the recycled aggregate replacement rate from the point of view of material wettability alone. Eq. (11) indicates that with the increase in $\cos \theta$, compressive stress P of the entire wall of pores also increases; the shrinkage of RAC increases as well.

$$P = P_c \cdot \cos \theta = \frac{2\sigma}{r} \cdot \cos \theta \quad (11)$$

where P is the compressive stress of entire wall; σ is surface water tension; r is the radius of the curved surface; and θ is the contact angle.

Table 3. Contact Angle

Experiment Number	k	$\cos \theta$	θ (°)
RC0	0.02897	0.2589	75.0
RC30	0.03348	0.2847	73.5
RC70	0.04186	0.3082	72.0
RC100	0.0470	0.3641	68.7
FA0	0.0470	0.3641	68.7
FA10	0.03503	0.3131	71.7
FA20	0.03167	0.3085	72.0
FA30	0.03083	0.2831	73.5

The contact angle increases with the increase in fly ash mixing amount. In other words, wettability gradually decreases; however, the decrease is not obvious mainly because capillary porosity is reduced when fly ash is added. When fly ash particles participate in hydration, the system hydration rate increases. Thus, the self-drying speed of the inner concrete increases with the increase in fly ash mixing amount.

Fig. (4) shows an SEM image of the hydration products of RAC with fly ash. The solid volume increases during the hydration of fly ash. Fly ash is squeezed around the cement hydration products, resulting in an original loose worm-like calcium-silicate-hydrate (C-S-H) creep. The C-S-H creep increases the density of the hardened cement paste structure, reduces the number of pores, and could cut off and refine these pores. In addition, the cement hydration product $\text{Ca}(\text{OH})_2$ is consumed during fly ash hydration. Fly ash hydration greatly reduces the $\text{Ca}(\text{OH})_2$ crystal content in the aggregate interface and cement paste and improves the uniformity and density inside the concrete (as shown in Fig. 4). The $\cos \theta$ value decreases with the increase in fly ash content. The compressive stress P of the entire wall of pores also decreases according to Eq. (8). Thus, the shrinkage value of RAC is small at the same intensity of capillary wall.

4. CONCLUSION

- (1) The addition of fly ash improves the porosity of RAC structures and reduces the wettability of the material, thereby possibly reducing the water diffusion rate of RAC. Thus, the addition of fly ash inhibits the shrinkage deformation of RAC.
- (2) The solid volume increases during fly ash hydration. Fly ash is squeezed around the cement hydration products, resulting in an original loose worm-like C-S-H creep.
- (3) The $\cos \theta$ value decreases with increased fly ash content from the point of view of θ alone.
- (4) The contact angle decreases with the increase in the recycled aggregate replacement rate, which may in turn increase the water diffusion rate and result in greater RAC shrinkage.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

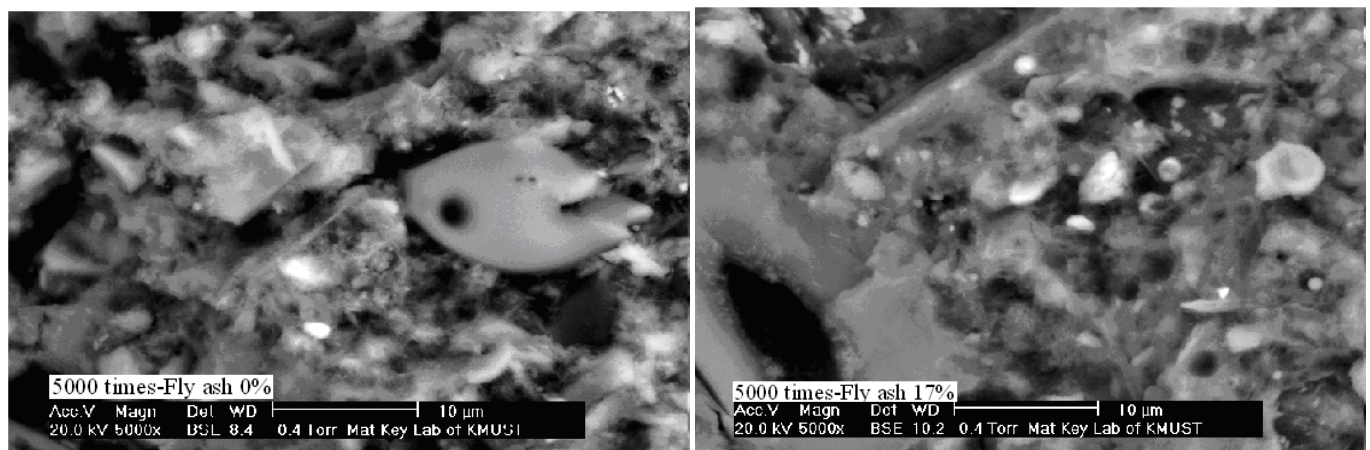


Fig. (4). SEM image of the hydration products of RAC with fly ash.

ACKNOWLEDGEMENT

This project was supported by the Project of National Natural Science Foundation of China (51202304), Natural Science Foundation Project of CQ CSTC (cstc2012jjA-50005).

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Received: July 20, 2013

Revised: September 15, 2013

Accepted: September 16, 2013

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