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"New Approach in Measuring Water Absorption of Recycled Aggregates"

By

Vivian W. Y. Tam[1], X. F. Gao[2], C. M. Tam[3] and C. H. Chan[3]

[1]Griffith School of Engineering, Griffith University, Australia.
[2] Faculty of Science, Xi'an Jiaotong University, China.
[3]Department of Building & Construction, City University of Hong Kong.

*Corresponding Author:

Dr. Vivian W. Y. Tam
Griffith School of Engineering,
Gold Coast Campus, Griffith University,
PMB50 Gold Coast Mail Centre,
Qld 9726, Australia.
Email: v.tam@griffith.edu.au.
Fax: (61)7-5552-8065 Tel: (61)7-5552-9278

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Abstract

With the increase in the use of recycled aggregate concrete, the demand on recycled aggregate (RA) is escalating. As such, the behaviour and characteristics of RA need to be clearly understood. In practice, the testing procedures of aggregates in Hong Kong follow those laid down in British Standard Institution (BSI) (BS: 812), which provide a good foundation for assessing properties of natural aggregates. As RA may have cement paste attached that may detach from the mass during sample preparation when repetitive soaking in water and drying are employed. Thus, the traditional testing approach for water absorption cannot give accurate results for RA, based upon which, errors in concrete mix designs may result. This paper proposes an innovative method for testing the water absorption of RA named Real-Time Assessment of Water Absorption (RAWA). The detailed testing procedure of the new method is illustrated with examples.

Keywords: recycled aggregate; water absorption; cement paste; and recycled concrete.

1. Introduction

There has been an overwhelming promotion of environmental management and sustainable development in Hong Kong in recent years. As a result, there is a growing awareness of environmental issues and the likely problems from deterioration of the environment. Construction by nature is not an environmentally friendly activity. Ofori [1], CIRIA [2], UNCHS [3] and Hill and Bowen [4] provided comprehensive reviews of the effects of construction activities on the environment. These effects include land use and land deterioration, resource depletion, waste generation and various forms of pollution [1,5].

Construction waste is a large percentage of solid waste. In the United Kingdom, more than 50% of waste deposited in a typical landfill comes from construction [6]. whilst 70 million tons of wastes result from construction and demolition (C&D) [7]. In Australia, about 14 million tons of waste is placed into landfill areas each year, and 44% of the waste is attributed to the construction industry [8,9]. 29% of solid-waste is from construction in USA [10] whilst 38% of solid waste comes from construction in Hong Kong [11].

Owing to the depletion of solid waste disposal areas, the Hong Kong government has been pressing to reduce waste generation in recent years. Construction, one of the most resource-consuming industries in Hong Kong [12-14], has to actively participate in waste reduction. The use of recycled aggregate has thus been strongly advocated [15-19]. The Civil Engineering Department of the Hong Kong Special Administrative Region (HKSAR) has set up a recycling plant to produce recycled aggregate in Tuen Mun Area 38 and the Buildings Department of HKSAR has issued a practice note on “Use of recycled aggregates in concrete”; and the Environment, Transport and Works Bureau has published a Technical Circular (Ref: 12/2002) entitled “Specifications facilitating the use of recycled aggregates”.

All aim at promoting the use of recycled aggregate and setting standards and practice guidelines for the product. The Architectural Services Department of HKSAR has examined the possibility of using 20% recycled aggregate for school projects and the Hong Kong Housing Authority of HKSAR and local universities are finding ways to improve the quality of recycled aggregate.

As a result, the properties and behaviors of recycled aggregate need to be explored and fully understood. Unlike ordinary aggregate, recycled aggregate is coated with patches of cement mortar remains that increase water absorption, prolong the mixing time and affect the strength of the recycled aggregate concrete (RAC). The remains of cement paste will affect the results of experiments which were designed for ordinary natural aggregate as prescribed by the British Standard Institution (BSI) [20].

2. Research Significance

This paper is intended to: (i) investigate the current BSI methodology in measuring water absorption of aggregate; (ii) examine the problems presented in measuring this property for recycled aggregate (RA); (iii) develop an alternative methodology to examine water absorption of recycled aggregate named Real-Time Assessment of Water Absorption (RAWA) in giving a more accurate and reliable measure; and (iv) explore the experimental works for RAWA with recycled aggregates and virgin aggregates.

3. Importance of Water Absorption of Aggregate

The overall porosity or absorptivity of aggregates depend either upon a consistent degree of particle porosity or represent an average value for a mixture of variously high and low absorption materials [21]. One of the marked physical differences between RA and natural aggregate results from higher water absorption rate. The higher water absorption of the coarse aggregate resulted from the higher absorption rate of cement mortar attached to the aggregate particles [22-24]. This characterizes concrete made with higher water absorption recycled aggregate reduced compressive strength and resistance to freezing and thawing than with ordinary aggregate [23].

Normally, recycled aggregate is more absorptive than natural aggregate. Water absorption lies around 3 to 10 percent for recycled aggregate and from less than 1 up to 5 percent for natural aggregates [25-29]. When this overall absorption is reasonably consistent among particles, such values are unlikely to be problematic in most concrete, providing that the average values are known and can be taken into account in the mix design and batching. Hence, it is important to know the water absorption rates of RA at the mix design stage. In some circumstances it has been thought necessary to place an upper limit on aggregate absorption.

4. Current Practices in Assessing Water Absorption

4.1 Current British Standard

According to BS:812 Part 2 [30], an aggregate sample of around 2 kilograms needs to be washed on a sieve in order to both remove fine particles and drain away the water. The prepared sample is then covered with water for 24 hours (h) ± 0.5 h to ensure that all the pores and voids inside the aggregate are filled with water. After that, the surface water of aggregate needs to be removed by a cloth or towel until the appearance of the suface looks damp. Then, the aggregate is weighed (Mass A) in a saturated surface-dried condition. The oven-dried mass of aggregate (Mass B) is then obtained after drying in an oven at 105 ± 5°C for 24 h ± 0.5 h. The following *Equation (1)* gives the water absorption:

$$\frac{100(A-B)}{B} \qquad \textit{Equation (1)}$$

Where *A* is the mass of the saturated surface-dried aggregate in air (in g); and *B* is the mass of the oven-dried aggregate in air (in g).

4.2. Problems

Based on our observations and experiences in testing the water absorption using the methodology prescribed by BS:812 Part 2 [30], three problems exist in testing recycled aggregate:

1. Drying at 105 ± 5°C to obtain the oven-dried mass of aggregate may remove water chemically incorporated in the crystal structure of compounds in the mortar attached to the aggregate. The water present in some of these compounds can be freed upon reaching temperature of more than 100°C [31]; for example, *Equation (2)* shows the effect in the removal of crystallized water:

   $$2(CaSO_4 \bullet \frac{1}{2} H_2O) \xrightarrow{\text{Heat}} 2CaSO_4 + H_2O \qquad \textit{Equation (2)}$$

   Therefore, removing the crystallized water will give a misleading level of water absorption of aggregate

2. The soaking time before reaching full saturation for recycled aggregate varies from the conditions of surface cement pastes on aggregate. Our experiments, the results of which are presented in a following section of this paper varies in relation to the nature of the aggregate surface.

3. The BSI approach requires surface-drying the aggregate with a cloth or towel. However, the soaking of aggregate in water may detach some cement paste sticking on the surface of aggregate which may be removed during drying thus significantly reducing the oven-dried mass of aggregate and restricting the accuracy of the testing result.

Based up on the above problems in using the current British Standard, an unrealistic result on water absorption value is obtained for recycled aggregate as a reduced mass of aggregate is used for the assessment due to flaking-off of some cement mortar attached on the surface of old aggregate. However, until now, no other alternative method has been available in providing an accurate assessment of water absorption of recycled aggregate.

5. New Assessment Methods

5.1 Real-Time Assessment of Water Absorption

To overcome the above problems, a new approach to assess the water absorption of recycled aggregate is needed. The following presents an alternative methodology named Real-Time Assessment of Water Absorption (RAWA), which provides an easier way to obtain the water absorption at different time intervals and without the need of soaking and drying the recycled aggregate, thus giving a more accurate result.

The major principle in determining the water absorption by RAWA is the same as the BSI approach: the percentage of water absorbed by the recycled aggregate. In RAWA, the oven-dried mass of aggregate (5 to 40mm) (Mass B) is obtained first by placing them in an oven at 75 ± 5°C; this removes the free water in the aggregate without losing the crystallized water. The temperature needs to be maintained for at least 24 h ± 0.5 h or longer until there is no further loss in weight of the sample. After that, the aggregate is placed into a pyknometer (see Figure 1) which is then fully filled with distilled water that is free from any impurity and dissolved air at time, T_0 (to ensure that the pyknometer is full, the entrapped air can be removed by rolling the bottle slowly) in an indoor environment of constant humidity (60-80%) and temperature (20-25^{o}C). The water levels resulted from time intervals of T_1, T_2, T_3 to T_s. and any drop in water level are noted which result from absorption of water by the aggregate and evaporation noted into the indoor environment.

Then, additional water is then added to the pyknometer. The whole set-up is weighed and the weights M_i at T_i are obtained. The mass difference of the whole set-up between T_i and T_{i-1} equals the water absorbed by the aggregate ($M_i - M_{i-1}$). Repeating this procedure at different time periods until no further change in mass or reduction in water level is obtained, indicated that the aggregate has reached a fully saturated condition at T_s. The mass of the whole set-up at T_s when compared with T_0 equals the mass of the saturated water of the aggregate.

<Figure 1>

The water absorption (as % of dry mass) at T_i can be calculated from *Equation (3)*:

$$\frac{100\left[\sum_{j=1}^{i}\left(M_j - M_{j-1}\right)\right]}{B} \qquad \textit{Equation (3)}$$

Where B is the oven-dried mass of the aggregate in air (in g); T_i is the time intervals by which the aggregate sample is immersed in water; and M_i is the mass of pyknometer and aggregate with the set-up full of water at T_i (in g).

The total water absorption (as % of dry mass) of the saturated surface-dried aggregate at T_s can be calculated from *Equation (4)*:

$$\frac{100\left[(M_s - M_0)\right]}{B} \qquad \textit{Equation (4)}$$

Where M_s is the mass of the whole set-up full of water at T_s; and M_0 is the mass of the set-up at T_0.

5.2. Experimental Results

This method is suitable for any size of aggregate (from 5 to 40mm), and the values of water intervals. The values of water absorption can be assessed at different time intervals and the accurate mass of the sample can be maintained. Examples for comparing the determination of the water absorption use samples from 10mm natural aggregate (Sample 1), recycled aggregates from Tuen Mun Area 38 recycling plant (Sample 2), a demolition site next to Victoria Harbour with around 30 years of service (Sample 3) and another demolition site surrounded by residential buildings and a shopping centre with around 35 years of services (Sample 4).

Three tests for each sample of aggregate were conducted. Table 1 summarizes the results of RAWA while Table 2 show the results of test 1 on the change in water absorption over time for Samples 1, 2, 3 and 4. The overall water absorption rates for the three tests of each sample of aggregate are close. This demonstrates the consistency of the approach in measuring water absorption rates of four types of aggregate. The nature of the change in water absorption over time can also be observed. A total of 96 and 120 hours of soaking is required for recycled aggregate from Samples 3 and 4 respectively to reach a stable reading, while only 24 hours of soaking is required for natural aggregate (Sample 1) and recycled aggregate from recycling plant (Sample 2). Therefore, this concludes that the standard twenty-four hours stipulated in the British Standards are not suitable for assessing water absorption rates of recycled aggregate. In general, the higher the content of cement mortar in the recycled aggregate, the longer the saturation time will take.

<Table 1>

<Table 2>

5.3 Benefits

In measuring water absorption using RAWA, there are two major benefits when compared with the traditional BS testing approach:

1. Using the traditional testing approach, the cement mortar sticking to the recycled aggregate can easily be dislodged during the repetitive soaking and drying processes. RAWA can help preserve all the mortar sticking to the recycled aggregate particles. A more accurate result can be obtained, based upon which, more accurate mix design and batching can be developed.
2. A standard of twenty-four hours for measuring water absorption under the traditional testing approach is not appropriate for recycled aggregate due to the different extent to which cement paste can be attached to the particles resulting from the crushing process. The experiments show that the time required to fully saturate the recycled aggregate depends on the mortar remaining on the aggregate. In most cases, measure the time required to fully saturate recycled aggregate takes more than twenty-four hours. RAWA can be used to measure time period required to fully saturate recycled aggregate under different surface conditions. Further, the results of the experiment show that the water absorption rate is larger in the first 5 hours. This produces up to 80% of the total water absorption. The results of the standard 24-hour measurement are only 5.72% and 8.28% compared to values of 5.92% and 8.72% for Samples 3 and 4 respectively. RAWA also helps mix designers in understanding the behaviour of recycled aggregate in a concrete mix.

6. Conclusions

In adopting recycled aggregate to produce recycled aggregate concrete, the properties and behaviors of recycled aggregate should be determined accurately. The current BSI method in assessing water absorption of aggregate is not suitable for recycled aggregate. Patches of cement pastes attached to the surface of recycled aggregate may affect water absorption in a manner different to conventional aggregate. Because of this, the standard duration of 24 hours of saturation is not suitable for recycled aggregate. In order to affect by the amount of cement paste sticking on the aggregate, it varies from site to site after crushing from which the recycled aggregate was generated. In order to obtain the water absorption rates and the corresponding soaking time, RAWA is proposed to provide values of water absorption at different time intervals. Further, the proposed method can avoid the removal of the cement paste during the soaking and drying process of the recycled aggregate sample. The new approach is simpler and more accurate in measuring the genuine water absorption rate of recycled aggregate. The method has been tested and proven to be a good alternative for measuring water absorption of recycled aggregate.

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Table 1: Summary of Results Collected from Real-Time Assessment of Water Absorption

Sample	Water Absorption (in % of dry mass)			
	Test 1	Test 2	Test 3	Average
1	0.78	0.76	0.78	0.77
2	2.67	2.64	2.59	2.63
3	5.92	5.76	5.81	5.83
4	8.72	8.77	8.74	8.74

Table 2: Water Absorption Obtained Using Real-Time Assessment of Water Absorption

	j	Time(h)	B				M_j				$M_j - M_{j-1}$				$\Sigma(M_j - M_{j-1})$				Water absorption (as % of dry mass)			
			Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4	Sample 1	Sample 2	Sample 3	Sample 4
	0	0	988.4	1,038	991.7	932	2,406.60	2,414.30	2,349.30	2,292.80	-	-	-	-	-	-	-	-	-	-	-	-
	1	0.08	988.4	1,038	991.7	932	2,411.40	2,435.00	2,393.10	2,360.30	4.80	20.70	43.80	67.50	4.80	20.70	43.80	67.50	0.49	1.99	4.42	7.24
	2	0.25	988.4	1,038	991.7	932	2,413.60	2,437.20	2,394.50	2,361.40	2.20	2.20	1.40	1.10	7.00	22.90	45.20	68.60	0.71	2.21	4.56	7.36
	3	0.5	988.4	1,038	991.7	932	2,413.80	2,437.90	2,397.90	2,362.60	0.20	0.70	3.40	1.20	7.20	23.60	48.60	69.80	0.73	2.27	4.90	7.49
	4	1	988.4	1,038	991.7	932	2,413.90	2,439.20	2,400.10	2,364.30	0.10	1.30	2.20	1.70	7.30	24.90	50.80	71.50	0.74	2.40	5.12	7.67
	5	2	988.4	1,038	991.7	932	2,414.00	2,440.00	2,401.60	2,365.70	0.10	0.80	1.50	1.40	7.40	25.70	52.30	72.90	0.75	2.48	5.27	7.82
	6	4	988.4	1,038	991.7	932	2,414.00	2,440.60	2,403.30	2,366.90	0.00	0.60	1.70	1.20	7.40	26.30	54.00	74.10	0.75	2.53	5.45	7.95
	7	8	988.4	1,038	991.7	932	2,414.10	2,441.00	2,404.50	2,368.00	0.10	0.40	1.20	1.10	7.50	26.70	55.20	75.20	0.76	2.57	5.57	8.07
	8	24	988.4	1,038	991.7	932	2,414.30	2,442.00	2,406.00	2,370.00	0.20	1.00	1.50	2.00	7.70	27.70	56.70	77.20	0.78	2.67	5.72	8.28
	9	27	988.4	1,038	991.7	932	2,414.30	2,442.00	2,406.30	2,370.40	0.00	0.00	0.30	0.40	7.70	27.70	57.00	77.60	0.78	2.67	5.75	8.33
	10	30			991.7	932			2,406.70	2,370.50			0.40	0.10			57.40	77.70			5.79	8.34
	11	32			991.7	932			2,406.90	2,370.60			0.20	0.10			57.60	77.80			5.81	8.35
	12	48			991.7	932			2,407.10	2,371.40			0.20	0.80			57.80	78.60			5.83	8.43
	13	51			991.7	932			2,407.30	2,371.50			0.20	0.10			58.00	78.70			5.85	8.44
Tj	14	54			991.7	932			2,407.50	2,371.60			0.20	0.10			58.20	78.80			5.87	8.45
	15	56			991.7	932			2,407.50	2,371.70			0.00	0.10			58.20	78.90			5.87	8.47
	16	72			991.7	932			2,407.70	2,372.90			0.20	1.20			58.40	80.10			5.89	8.59
	17	75			991.7	932			2,407.70	2,373.00			0.00	0.10			58.40	80.20			5.89	8.61
	18	78			991.7	932			2,407.70	2,373.10			0.00	0.10			58.40	80.30			5.89	8.62
	19	80	-	-	991.7	932	-	-	2,407.70	2,373.20	-	-	0.00	0.10	-	-	58.40	80.40	-	-	5.89	8.63
	20	96			991.7	932			2,408.00	2,373.80			0.30	0.60			58.70	81.00			5.92	8.69
	21	99			991.7	932			2,408.00	2,373.90			0.00	0.10			58.70	81.10			5.92	8.70
	22	102				932				2,373.90				0.00				81.10				8.70
	23	104				932				2,374.00				0.10				81.20				8.71
	24	120				932				2,374.10				0.10				81.30				8.72
	25	123			-	932			-	2,374.10			-	0.00			-	81.30			-	8.72
	26	126				932				2,374.10				0.00				81.30				8.72
	27	128				932				2,374.10				0.00				81.30				8.72
	28	144				932				2,374.10				0.00				81.30				8.72

Note: B is the oven-dried mass of the aggregate in air (in g); T_i is the time intervals by which the aggregate sample is immersed in water; and M_i is the mass of pyknometer and aggregate with the set-up full of water at T_i (in g).

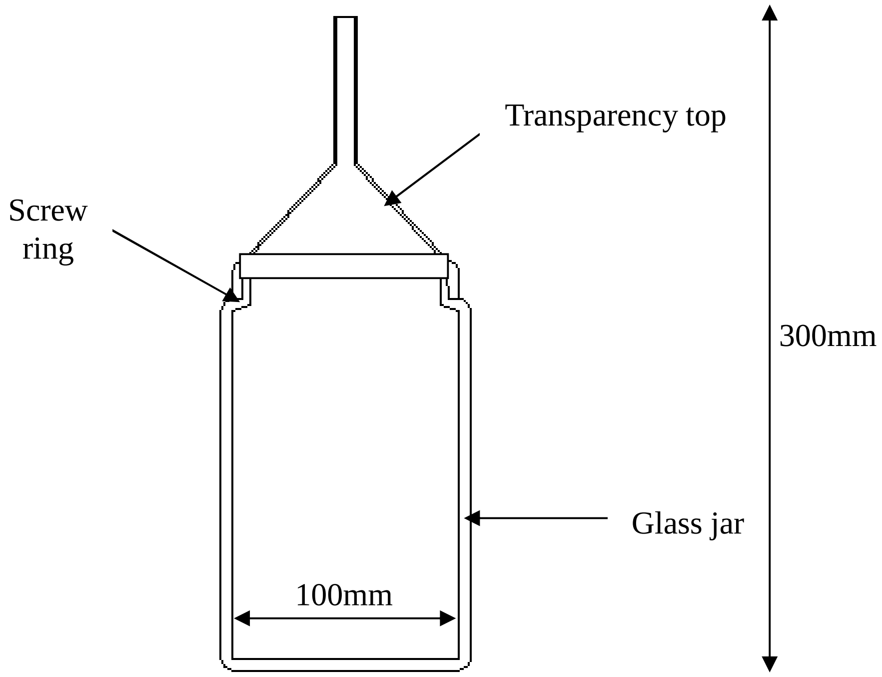

Figure 1: Apparatus for Obtaining Water Absorption by

Real-Time Assessment of Water Absorption