Properties of porous concrete from waste crushed concrete (recycled aggregate)

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HIGHLIGHTS

- Recycled aggregate porous concrete properties investigated.
- Higher total void ratio and water permeability exhibited by recycled aggregate.
- Polymer modification significantly improved strength properties of recycled aggregate porous concrete.
- Use of recycled aggregate along with optimum content of polymer produced acceptable porous concrete.

ARTICLE INFO

Article history:
Received 8 November 2012
Received in revised form 10 April 2013
Accepted 11 June 2013
Available online 7 July 2013

Keywords:
Porous concrete
Recycled aggregate
Permeability
Compressive strength
Flexural strength
Polymer–cement ratio
Total void ratio

ABSTRACT

The purpose of this study was to develop porous concrete with acceptable permeability and strength using recycled aggregate from waste crushed concrete. The optimum mix proportions were employed to prepare porous concretes using normal and recycled aggregates. Tests carried out on porous concrete were: void ratio, coefficient of permeability, compressive and flexural strengths. The effect of recycled aggregate on total void ratio, strength and permeability was examined. Styrene butadiene rubber-based redispersible polymer powder and latex were introduced to mixtures to improve strength properties. The total void ratio of porous concrete incorporating recycled aggregate was larger than that of porous concrete with normal aggregate. The addition of polymer modification resulted in a slight decrease in total void ratio regardless of type of aggregate. The compressive strength of porous concrete using recycled aggregate was lower than the one using normal aggregate. However, the compressive strengths of porous concretes using normal and recycled aggregates were significantly improved by 57% and 79% respectively, due to polymer modification. The use of recycled aggregate along with optimum content of polymer could produce acceptable porous concrete with both enough drainage and strength properties.

1. Introduction

The use of construction waste as a source of aggregate for the production of new concrete has become more common in recent years. The increasing cost of landfill, and the scarcity of natural resources for aggregate, encourages the use of waste from construction sites as a source of aggregates. Recycled aggregate from construction and demolition wastes could be an alternative to primary (normal) aggregates in construction, particularly recycled aggregate from waste crushed concrete from demolished concrete buildings can make up 75% of concrete [1]. Recyling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. It conserves natural resources and reduces the space required for the landfill disposal. The enormous quantities of demolished concrete available at various construction sites can easily be recycled as aggregate and used in concrete. In general, applications for waste crushed concrete without any processing include many types of general bulk fills, bank protection, base or fill for drainage structures, road construction and noise barriers and embankments [2]. Extensive research and development on reuse of waste crushed concrete (recycled aggregate) is going on globally to prove its feasibility, economic viability and cost effectiveness [3,4].

Most economical means to utilize recycled aggregate could be porous concrete which uses more than 80% aggregates. Porous concrete contains little or no fine aggregate, using an adequate amount of cement paste to coat and bind the aggregate particles to create a
system of high porosity and interconnected voids to quickly drain off water, its porosity depends upon application and size of aggregate. Porous concrete (no-fines concrete) is a unique and effective environmentally friendly material that is being extensively developed and used for last four decades in North America, Europe and Japan in various applications such as to reduce the amount of runoff water and improve the water quality near pavements and parking lots [5–10]. Due to water-permeating, water-draining, and water-retaining performances of porous concrete, it has been utilized in road pavement, sidewalks, parks and building extension, as well as for plant bedding and permeable gutters [5,11–15]. Unfortunately, no technical data and information are available on development activities and applications of porous concrete in South East Asia particularly, Malaysia. Located near the equator, Malaysia’s climate is categorized as equatorial being hot and humid throughout the year. The average rainfall is 2500 mm a year [16], necessitating the introduction and popularization of porous concrete technology in Malaysia in order to minimize the adverse effects of heavy rainfall as floods and mudslides.

The purpose of this research study is to entirely replace normal aggregate with recycled aggregate into porous concrete to create a very sustainable concrete product for pavement and for precast porous concrete applications. Another aim of this research study is to explore the characteristics of porous concrete using local materials while keeping in view the climatic conditions of the region. Porous concrete is prepared using recycled coarse aggregate from waste demolished reinforced concrete structure (residential apartment buildings) and results are compared with the normal aggregate porous concrete. In general, porous concrete shows low strength due to large void ratio, particularly, when recycled aggregate is used. One of the effective techniques to enhance the strength properties of porous concrete could be to use polymeric admixtures such as polymer latexes or dispersions [16,17]. Huang et al. [6] and Aamer Rafique Bhutta et al. [10] also reported that the addition of polymer significantly improves workability and strength properties of porous concrete at relatively lower water–cement ratio. Therefore, latex polymer styrene butadiene rubber (SBR) based redispersible polymer powder and latex are selected and incorporated into the concrete mixture in order to improve the strength of porous concrete using recycled aggregate.

2. Experimental work

2.1. Materials

Ordinary Portland cement was used in this study. Crushed granite aggregate and waste crushed concrete were used as normal and recycled aggregates, respectively. A source of recycled aggregate is shown in Fig. 1. The crushing of waste concrete was carried out inside the laboratory. Recycled aggregate was not washed and used as is. Table 1 shows the properties of aggregates. The aggregate size distribution of normal and recycled aggregates is demonstrated in Fig. 2. Commercially available styrene butadiene rubber (SBR) based redispersible polymer powder (RPP) and latex emulsion (Latex) were used as polymeric admixtures into the mixtures. The aim was to enhance the strength of porous concrete, particularly the one incorporating recycled aggregate. The properties of polymeric admixtures are given in Table 2.

2.2. Mix proportions

The porous concrete mixtures comprised of Portland cement, water and coarse aggregate containing normal and recycled aggregates. To improve the strength of porous concrete, latex polymer in powder and liquid forms were used. Various preliminary mixes were prepared to obtain the optimum mix proportion of porous concrete. Polymer was first mixed with mix design water and no extra water was added. The optimum mix proportions are presented in Table 3. The polymer–cement ratios (P/C) of 0%, 3% and 5% by mass of cement were used. Porous concrete has already low water–cement ratio. Therefore, it is important to maintain the mix design water content in porous concrete for proper mixing. High water absorption of recycled aggregate may result in lower water content in the mix. This could affect the mixing adversely and the produced concrete will have large void ratio, low strength and may not fulfill the specific mix design requirements. Therefore, recycled aggregate used were first pre-soaked for 12 h prior to casting. Aim was to avoid the absorption of mix water by the aggregates in fresh mixture.

2.3. Specimens preparation

The specimens were prepared at ambient laboratory temperatures according to the JCI Standard (draft) – “Method of Making Porous Concrete Specimens (draft), Report on Eco-Concrete Committee on Design, Construction and Recent Applications of Porous Concrete”. They were then cured at room temperature for 1-day. According to this method, mixed porous concrete was filled into moulds up to one third of its height and subjected to 25 times hand tamping. The same procedure was applied for the two third and complete fill-ups. Placing and consolidating the porous concrete in molds can cause excessive void and strength losses, thus adversely affecting the test results. Porous concretes contained SBR-based latex and RPP. It is well known that for an optimum film formation, a dry cure is required [17]. On the other hand, cement hydration only takes place in the presence of sufficient water. Since porous concrete has low W/C, therefore, both the specimens were placed in water for 5-d and then subjected to 25 ± 1 °C and 60% R. H. for 22-d. The specimens were prepared as per JCI Standard (Method of Making Porous Concrete Specimens (draft), Report on Eco-Concrete Committee at ambient laboratory temperature) [19]. The cube specimens sized 150 × 150 × 150 mm for compressive strength, beam specimens sized (100 × 100 × 400 mm) for flexural strength, cylinder specimens sized (φ100 × 200 mm) for total void ratio and water permeability tests. To obtain mean value, three identical concrete specimens were prepared for each test.

3. Tests

The tests carried out were: total void ratio, compressive strength, flexural strength and co-efficient of water permeability.

3.1. Total void ratio

JCI Test Method (Report on Eco-Concrete Committee for Void Ratio of Porous Concrete (draft) was employed to determine the total void ratio of porous concrete cylinders (φ100 × 200 mm) [19]. The total void ratio was obtained by dividing the difference between the initial mass (M1) of the cylinder specimen in the water and the final mass (M2) measured following air drying for 24 h with the specimen volume (V), where ρM is the density of water.
Table 1
Physical properties of aggregate.

<table>
<thead>
<tr>
<th>Type</th>
<th>Gradation (mm)</th>
<th>Density (g/cm³)</th>
<th>Water absorption (%)</th>
<th>Absolute volume (%)</th>
<th>Unit weight (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal aggregate</td>
<td>5–20</td>
<td>2.55</td>
<td>1.2</td>
<td>55.6</td>
<td>1620</td>
</tr>
<tr>
<td>Recycled aggregate</td>
<td>5–22</td>
<td>2.34</td>
<td>4.6</td>
<td>57.5</td>
<td>1542</td>
</tr>
</tbody>
</table>

* Absolute volume = aggregate mass/density.

Table 2
Properties of redispersible polymer powder (RPP) and latex.

<table>
<thead>
<tr>
<th>Type</th>
<th>Appearance</th>
<th>Particle size (µm)</th>
<th>Solid content (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPP</td>
<td>Grayish-white</td>
<td>0.15</td>
<td>50</td>
<td>7–8</td>
</tr>
<tr>
<td>Latex</td>
<td>Milky white</td>
<td>200</td>
<td>49</td>
<td>10–11</td>
</tr>
</tbody>
</table>

Table 3
Mix proportions of porous concrete.

<table>
<thead>
<tr>
<th>Type</th>
<th>W/C (%)</th>
<th>Void ratio (%)</th>
<th>Mix proportions (kg/m³)</th>
<th>Water</th>
<th>Cement</th>
<th>Aggregate</th>
<th>Polymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal aggregate</td>
<td>30</td>
<td>20–25</td>
<td>85</td>
<td>823</td>
<td>1620</td>
<td>0</td>
<td>14.0</td>
</tr>
<tr>
<td>Recycled aggregate</td>
<td>78</td>
<td>260</td>
<td>1542</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

Fig. 2. Aggregate size distribution of normal and recycled aggregates.

The specimens were placed inside the cage immersed in clean water at room temperature. The mass of the specimen in water (M1) was determined after removing the air bubbles on the particle surfaces and between the particles of specimen. The equation used to obtain total void ratio (A) is as follows:

\[ A(\%) = 1 - \left( \frac{(M2 - M1)}{\rho M V} \right) \times 100 \]

3.2. Coefficient of water permeability

The coefficient of water permeability of porous concrete was determined in accordance with JCI Test Method for Permeability of Porous Concrete (draft), Report on Eco-Concrete Committee [19]. Fig. 3 demonstrates testing procedures for the water permeability of porous concrete. Water permeability of porous concrete was determined over a period of 30 s under a water head of 200 mm. The water permeability coefficient was calculated using the following equation:

\[ K_r = \frac{H}{A} \times \frac{Q}{(t_2 - t_1)} \]

where \( K_r \): permeability coefficient (cm/s); \( H \): length of specimen (cm); \( Q \): amount of discharge water from \( t_1 \) to \( t_2 \) (cm³); \( h \): difference of water head; \( t_2 - t_1 \): time (s); \( A \): area of cross section of cylindrical specimen (cm²).

3.3. Compressive and flexural strengths

The compressive strength was performed according to JIS (Japanese Industrial Standard) A 1108 (Method of Test for Compressive Strength of Concrete). The flexural strength test was conducted in accordance with JIS A 1106 (Method of Test for Flexural Strength of Concrete) which is similar to ASTM C 78/C 78M-10e1 “Standard Test Method for Flexural Strength of Concrete” (Using Simple Beam with Third-Point Loading).

4. Results and discussion

4.1. Effect of recycled aggregate and polymer on total void ratio

Fig. 4 shows the total void ratio of porous concretes using normal and recycled aggregates and the effect of polymer modification on total void ratio. The total void ratio of porous concrete using recycled aggregate was higher than that of porous concrete with normal aggregate. Generally, porous concrete with recycled aggregate contains not only the original aggregate, but also hydrated cement paste which reduces the specific gravity and increases the porosity compared to similar normal aggregate. It was seen that the total void ratio of porous concrete with recycled aggregate was within the acceptable range of 22–27%. Moreover, the addition of polymer modification resulted in a slight decrease in total void ratio regardless of type of aggregate. However, the total void ratio of porous concrete incorporating recycled aggregate was higher than that of porous concrete having normal aggregate. It is due to the more internal friction among recycled aggregates provided by the poor workability of recycled aggregate porous concrete which is lower than the normal aggregate porous concrete. The workability of fresh concrete would be affected by the presence of recycled aggregate. This phenomenon is mainly attributed to the angular shape and rough surface texture of the recycled aggregates. The high water absorption decreases the workability of the fresh concrete due to the presence of old mortar in the recycled aggregate. The workability of fresh porous concrete with polymer modification has been determined using slump and slump-flow test in one of the previous studies [for details, see Ref. [10]]. Therefore, an addition of polymer modification into mixtures was made to improve the workability of cement paste for porous concretes. It was also observed that workable cement paste coated over the recycled aggregate and kept in contact with each aggregate to minimize the total void ratio. The difference between the total void ratios of porous concretes using normal and recycled aggregates is due to the nature of polymer.

4.2. Effect of recycled aggregate and polymer on compressive strength

The compressive strength of porous concretes using normal and recycled aggregates is shown in Fig. 5. At the same void ratio, a reduction in strength is observed for porous concrete using recy-
cled aggregate compared to porous concrete incorporating normal aggregate. This could be due to reduction of bonding between aggregate and cement paste when using recycled aggregate and partly by the increased void ratio. Generally, it is expected that the compressive strength of porous concrete is related to the strength of aggregate and total void ratio. A polymer modification is considered and incorporated into the mixtures to improve the strength of porous concrete, particularly, the one using recycled aggregate. It is evident that the addition of both RPP and latex could increase the compressive strength of all porous concretes as well as increase the contact area between neighbouring aggregate particles, more importantly; these commingle along with cement hydration products and create two interpenetrating matrices which work together, resulting in improved compressive strength [6,17]. The mean value of compressive strength of porous concrete is fairly uniform in three specimens as depicted by variation bars.

The compressive strengths of porous concretes using normal and recycled aggregates improved significantly due to polymer modification. At P/C ratios of 3% and 5% for RAA, the compressive strength of porous concretes improved 26% and 57% for normal aggregate, and 47% and 79% for recycled aggregate. The compressive strength was also enhanced using latex with the same P/C ratios and increments in strength were 19% and 47% for normal aggregate, and 43% and 68% for recycled aggregate. It is believed that the addition of RPP gave greatly improved internal cohesion and water retention between cement matrix and aggregate and increased the bonding force between neighbouring aggregate particles [10].

4.3. Effect of recycled aggregate and polymer on relationship between total void ratio and compressive strength

Fig. 6 represents the effect of aggregate type on relationship between total void ratio and compressive strength of porous concrete without polymer. The variation in total void ratio is the mean of three identical specimens. Effect of polymer type (polymer–cement ratio: 5%) on relationship between total void ratio and compressive strength of porous concrete using recycled aggregate is
shown in Fig. 7. Regardless of aggregate and polymer type, the compressive strengths of all porous concretes were decreased with an increase in total void ratio. All Porous concretes having the total void ratio of 23–28% showed an almost linear relationship between compressive strength and total void ratio.

4.4. Effect of recycled aggregate and polymer on coefficient of water permeability

According to Fig. 8, the effect of recycled aggregate and polymer on coefficient of water permeability is similar to that on total void ratio. It is evident from Fig. 8 that all porous concretes showed water permeability values of 2.4–3.7 cm/s, which is high enough to be used for drainage purpose in pavement or precast product application [18]. The recycled aggregate showed consistent influence on the water permeability of porous concretes. Porous concrete prepared using recycled aggregate exhibited larger permeability values. Although the addition of RPP and latex could lead to a further reduction in permeability, however, the permeability values are comparable and acceptable compared to the general requirement of drainage [6].

4.5. Effect of recycled aggregate and polymer on relationship between total void ratio and coefficient of water permeability

Fig. 9 exhibits the effect of aggregate type on relationship between total void ratio and coefficient of water permeability of porous concretes. Fig. 10 gives the effect of polymer type (polymer–cement ratio: 5%) on relationship between total void ratio and coefficient of water permeability of porous concrete using recycled aggregate. Regardless of aggregate and polymer type, the coefficient of water permeability for all porous concretes became larger as the total void ratio increased. In the range of 23–28% total void ratio, the coefficient of water permeability of all porous concretes increased linearly.

4.6. Effect of recycled aggregate and polymer on flexural strength

Fig. 11 exhibits the effect of recycled aggregate and polymer on the flexural strength of porous concretes. The effects of both aggregate and polymer are evident. The use of recycled aggregate in porous concrete decreased the flexural strength than that of normal aggregate but the introduction of polymer modification enhanced the flexural strength in all porous concretes. As mentioned above, this is attributed to the polymer network formed during the commingling and inter-penetration of the polymer and cement hydra-
conclusions can be drawn: 

(1) The total void ratio of porous concrete incorporating recycled aggregate was higher than those having normal aggregate. The addition of polymer modification resulted in a slight decrease in total void ratio regardless of type of aggregate. The total void ratios were achieved within the acceptable range of 22–28% for recycled aggregate porous concretes.

(2) The compressive strength for porous concrete using recycled aggregate was lower than the normal aggregate porous concrete. However, the strength was significantly improved due to polymer modification by 57% for natural aggregate and 79% for recycled aggregate at P/C of 5% for RPP.

(3) All the porous concretes showed coefficient of water permeability values between 2.4 to 3.7 cm/s, which is high enough to be used as a drainage pavement.

(4) Regardless of type of aggregate and polymer, results showed an almost linear relationship between the compressive strength and total void ratio, and between coefficient of permeability and total void ratio for all porous concretes.

(5) The addition of polymer increases the workability of cement paste and allows the aggregate to flow better. This decreases the void ratio and increases the strength of porous concrete.

(6) Use of recycled aggregate along with polymer modification could produce acceptable porous concrete having both enough drainage and strength properties.

5. Conclusions

An experimental study was conducted to investigate the properties of polymer-modified porous concretes prepared from normal and recycled aggregates. The effects of using recycled aggregate and polymer modification on total void ratio, permeability and strength were evaluated. Based on this study, the following conclusions can be drawn:

- The total void ratio of porous concrete incorporating recycled aggregate was higher than those having normal aggregate. The addition of polymer modification resulted in a slight decrease in total void ratio regardless of type of aggregate. The total void ratios were achieved within the acceptable range of 22–28% for recycled aggregate porous concretes.
- The compressive strength for porous concrete using recycled aggregate was lower than the normal aggregate porous concrete. However, the strength was significantly improved due to polymer modification by 57% for natural aggregate and 79% for recycled aggregate at P/C of 5% for RPP.
- All the porous concretes showed coefficient of water permeability values between 2.4 to 3.7 cm/s, which is high enough to be used as a drainage pavement.
- Regardless of type of aggregate and polymer, results showed an almost linear relationship between the compressive strength and total void ratio, and between coefficient of permeability and total void ratio for all porous concretes.
- The addition of polymer increases the workability of cement paste and allows the aggregate to flow better. This decreases the void ratio and increases the strength of porous concrete.
- Use of recycled aggregate along with polymer modification could produce acceptable porous concrete having both enough drainage and strength properties.

Acknowledgments

The authors are grateful to the Ministry of Higher Education, Malaysia (MoHE) and Research Management Centre (RMC), Universiti Teknologi Malaysia (UTM) for financial support under Grant: Q.J130000.7122.01J76. The authors are also thankful to the staff of Materials & Structures Laboratory, Faculty of Civil Engineering for the facilities and support for experimental work.

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