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Mechanical properties of polymer-modified porous concrete

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Abstract. In this research work, polymer-modified porous concretes (permeable concretes) using polymer latex and redispersible polymer powder with water-cement ratio of 30 %, polymer-cement ratios of 0 to 10 % and cement content of 300 kg/m^3 are prepared. The porous concrete was tested for compressive strength, flexural strength, water permeability and void ratio. The cubes size of specimen is 100 mm ×100 mm × 100 mm and 150 mm × 150 mm × 150 mm while the beam size is 100 mm × 100 mm × 500 mm was prepared for particular tests. The tests results show that the addition of polymer as a binder to porous concrete gives an improvement on the strength properties and coefficient of water permeability of polymer-modified porous concrete. It is concluded from the test results that increase in compressive and flexural strengths and decrease in the coefficient of water permeability of the polymer-modified porous concrete are clearly observed with increasing of polymer-cement ratio.

1. Introduction

Porous concrete made from 80% of course aggregates which contains little or no fine aggregate. Therefore, an adequate amount of cement paste was used to coat and bind the aggregate particles to create a system of high porosity of the concrete. The porosity is depends upon the application of the concrete and size of aggregate used. Porous concrete is concrete which is designed to have many voids according to it applications such as to reduce the amount of runoff water and improve the water quality near pavements and parking lot [1–6]. There are a numbers of alternate names for porous concrete including permeable concrete, porous concrete pavement and pervious concrete. All names basically giving the same meaning which is the form of concrete is permeable rather than solid state. Porous concrete has been developing as an environmentally friendly material in in North America, Europe and Japan since1980's. 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, 7-11]. Unfortunately, limited 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

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year [12], 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 issues rise during the end of year in Malaysia is heavy raining and flooding which cause a big chaos to Malaysian citizen. Porous concrete pavement can potentially infiltrate storm water at the source which will allow the oils from cars and trucks to biodegrade safely, improve driving safety, reduce traffic noise and also reduce urban temperatures.

2. Experimental Program

2.1 Materials

The cement used in the study was ordinary Portland cement (OPC) obtained from Holcim Cement Manufacturing Company of Malaysia, conforming to ASTM C150 standard. Crushed granite aggregate with the size between 5 mm to 10 mm was used. The aggregate occupied 60 to 80 percent of the concrete volume. The coarse aggregate is air dried to obtain saturated surfaces dry condition to ensure the water cement ratio is not affected. As for the binder, two types of commercially available styrene butadiene rubber (SBR) based redispersible polymer powder (RPP) and latex emulsion (Latex) were used as polymeric admixtures into the porous concrete. The aim was to enhance the strength of porous concrete. The percentage of polymer added is 0 %, 3 % and 5 % over percentage of cement. The properties of polymeric admixtures are given in Table 1.

Table 1. Properties of redispersible polymer powder (RPP) and latex.

Type of polymer	Appearance	Particle size (µm)	Density (g/cm^3)	Solid content (%)	pH
RPP	Grayish-white powder	0.15	0.50	50	7–8
Latex	Milky white	200	0.98	49	10–11

2.2 Mix Proportion

The porous concrete mixtures comprised of Portland cement, water and coarse aggregate. 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 2. The polymer–cement ratios (P/C) of 0 %, 3 % and 5 % by mass of cement were used. Porous concrete has low water–cement ratio. Therefore, it is important to maintain the mix design water content in porous concrete for proper mixing.

Table 2. Mix proportions of porous concrete.

Type of concrete	W/C (%)	Void ratio (%)	Aggregate content (%)	Mix proportions (kg/m^3)			
				Water	Cement	Aggregate	Polymer
Normal	30		80	89	300	1640	-
RPP							3%
							5%
Latex							3%
							5%

2.3 Specimen Preparation

The specimens were prepared at ambient laboratory temperatures according to the JCI Standard – ‘‘Method of Making Porous Concrete Specimens (draft), Report on Eco-Concrete Committee on

Design, Construction and Recent Applications of Porous Concrete''. The specimens 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 moulds can cause excessive void and strength losses, thus adversely affecting the test results. Porous concretes contained SBR-based latex and RPP is well known for an optimum film formation, thus, a dry cure is required [13]. 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 cube specimens size is 100×100×100 mm for compressive strength, beam specimens sized (100×100×400 mm) for flexural strength and cylinder specimens sized (ø100×200 mm) for total void ratio and water permeability tests. To obtain mean value, three identical concrete specimens were prepared for each test.

3. Experimental Tests

3.1 Total void ratio test

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 (ø10 × 200 mm) [14]. 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. 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:

$$A\ (\%) = 1 - [(M2 - M1)/\rho w] / V1 \times 100 \tag{1}$$

3.2 Coefficient of Water permeability

Permeability is an important parameter of porous concrete since the material is designed to perform as drainage layer in pavement structures. Due to the high porosity and the interconnected air voids path, Darcy's law for laminar flow is no longer applicable for porous concrete. In this study, a permeability measurement device and method developed by Huang et al. for drainable asphalt mixture similar to porous concrete in function were used [5]. This test is done according to JCI-SPO3-1 (Japan Concrete Institute) standard.

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 Discussions

4.1 Effect of polymer-modified porous concrete on total void ratio

Total voids ratio is defined as the percentage of the total volume of voids to the total volume of specimen. Void ratio is very important in porous concrete because more void present, it will gives lower strength to porous concrete. Same as conventional concrete, present of void will effect the strength of the concrete. Figure 1 shows the relationship between total void ratio and type of porous concrete. The result shows that the type admixture added in porous concrete effect the void content. Normal porous concrete without polymer shows high void ratio than polymer-modified porous concrete. By adding polymer in porous concrete mixture, the void ratio can be decrease and as a results, it will produce high strength of porous concrete. The redispersible polymer in powder form has

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somehow lower the total void ratio due to its properties that bind the cement paste well and also produce a sticky mixture. Thus, it lower the total void percentage of polymer-modified porous concrete.

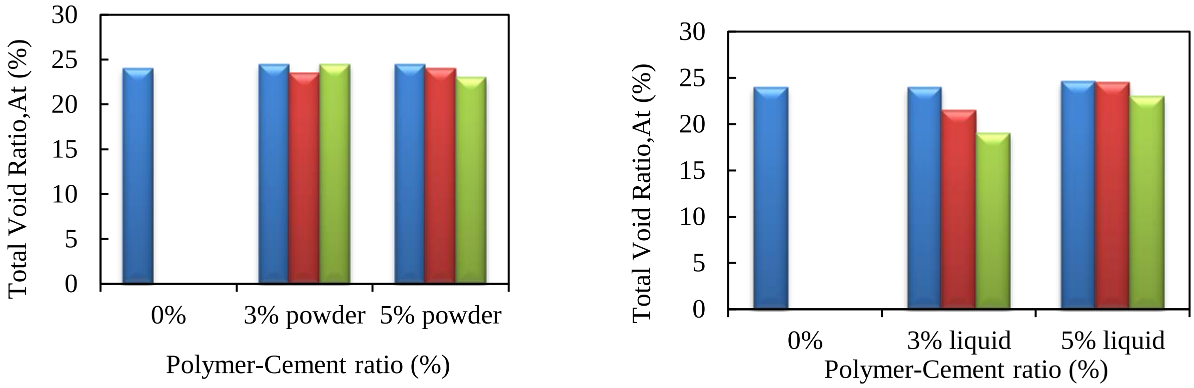

Figure 1. Relationship between total void ratio and polymer-cement ratio.

4.2 Compressive strength

Figure 2 shows the compressive strength of the various polymer-modified porous concrete. Figure shows that by adding polymer admixture into the mixture, the strength of porous concrete is increase. Powder type of polymer gives higher strength compare to liquid type polymer. The additional of 5% polymer powder into the mixture was resulted in higher compressive strength compared to 3% of polymer powder content. This is due to the adequate amount of polymer that binds the paste together to produce stronger bonding in the concrete. A polymer modification is considered and incorporated into the mixtures to improve the strength of porous concrete. It is evident that the addition of both RPP in powder form and liquid latex polymer could increase the compressive strength of porous concretes as well as increase the contact area between neighbouring aggregate particles. Moreover these polymers react along with cement hydration products and create two interpenetrating matrices which work together, resulting in improvement of compressive strength [2,13].

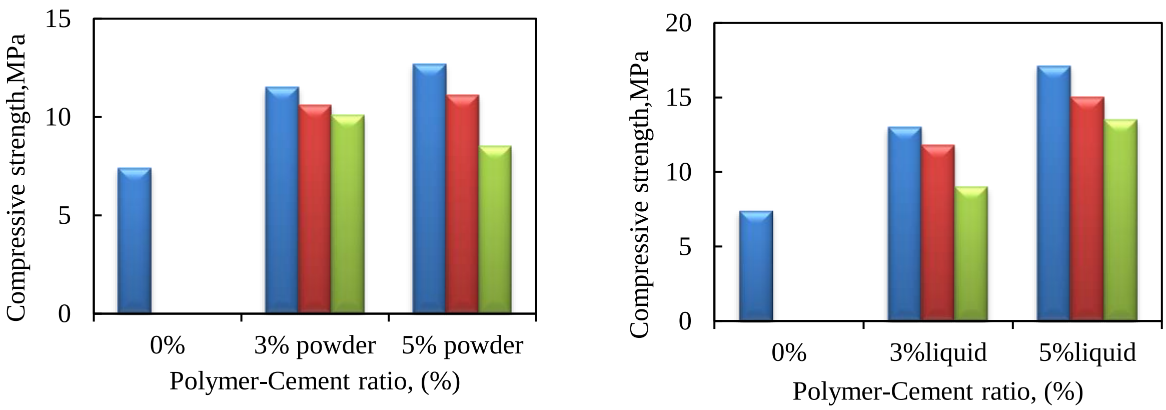

Figure 2. Relationship between compressive strength and polymer-cement ratio

4.3 Flexural strength

Figure 3 exhibits the effect of polymer addition on the flexural strength of porous concretes. The introduction of polymer modification enhanced the flexural strength in all porous concretes. As mentioned, this is attributed to the polymer network formed during the commingling and inter-penetration of the polymer and cement hydra tion products [13]. Unlike the brittle cement paste, the polymer network is relatively strong in tension zone, which contributes significantly to the flexural strength of porous concrete.

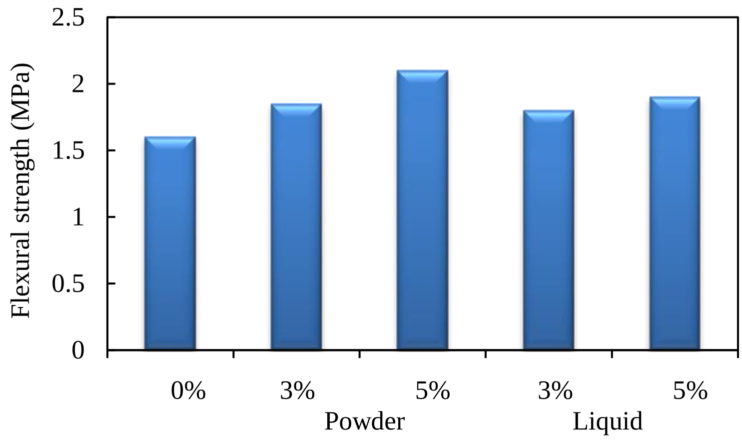

Figure 3. Relationship between flexural strength and polymer-cement ratio.

4.4 Coefficient of Permeability

Figure 4 represents the coefficient of permeability of porous concrete with different percentage of polymer admixtures. Porous concrete shows water permeability values between 2.4 to 3.7 cm/s, which is adequate to be used for drainage purpose in pavement or precast product application [15]. The addition of powder and liquid polymer could lead to a further reduction in permeability as shown by 5% of liquid addition, the coefficient of permeability is the higest compared to others porous concrete.

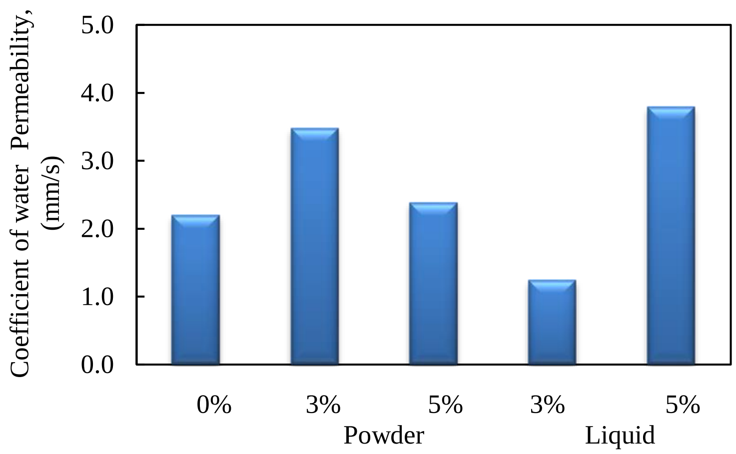

Figure 4. Relationship between coefficient of permeability and polymer-cement ratio.

Figure 5 exhibits the relationship between total void ratio and coefficient of water permeability of porous concretes. Regardless of polymer types, 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.

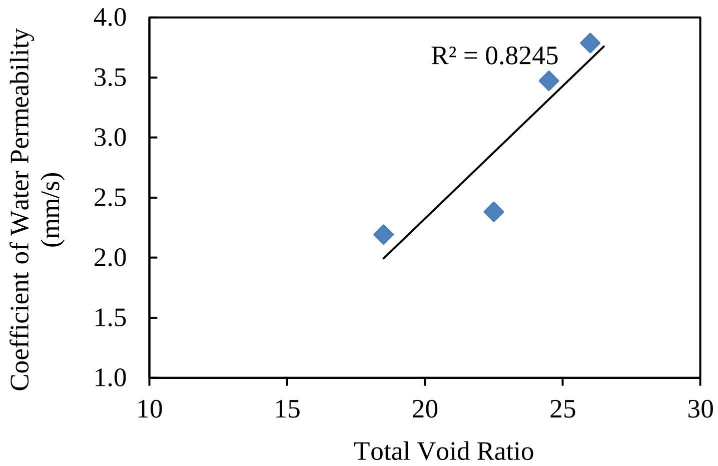

Figure 5. Relationship between coefficient of permeability and total void ratio.

5. Conclusions

An experimental study was conducted to investigate the mechanical properties of polymer-modified porous concretes. The effects of using different types of polymer on total void ratio, permeability and strengths were evaluated. Based on this study, the following conclusions can be drawn:

1. Use of the polymer latex and redispersible polymer powder could produce acceptable porous concrete with adequate strength properties and water permeability.
2. Strength properties of polymer-modified porous concretes are significantly improved by the polymer modification.
3. There is no significant change in void ratio of polymer-modified porous concretes compared to unmodified (normal) porous concrete. That means without changing void ratio of porous concrete, the strength can be improved by the polymer-modification.
4. Polymer powder show high compressive strength than liquid polymer.
5. Coefficient of permeability is directly proportional to void ratio.

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