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Effect of curing on the compressive strength development in structural grades of geocement concrete

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HIGHLIGHTS

- Structural grades geocement concretes require reduced binder and water contents.
- Fly ash and slag proportions in geocement influences the mix design.
- Strength improvement for geocement concretes is 15–20% from 28 to 90 days.
- Geocement concretes develop up to 45% of 28-day ambient strength in 4 h at 70 °C.
- Heat-cured strength is linearly related to ambient strength for geocement concretes.

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ABSTRACT

Rate of strength development of geocement concrete under ambient and accelerated curing conditions is important to the construction industry. This paper reports the results of an experimental investigation into the development of compressive strength with age for Grades 40, 50, 65 and 80 geocement concretes subjected to ambient (20 °C) and accelerated (70 °C for 4 and 24 h) curing conditions. Two types of powder-activated geocement, having fly ash: slag (ground granulated blast furnace) weight ratio, of 7:3 and 4:6, were used to produce four grades of geopolymer concrete mixtures. For comparison, similar grades of ordinary Portland cement concrete were also investigated for their strength development under similar curing conditions. At ambient curing condition, similar to Portland cement concretes, geocement concretes showed gradual strength development with age at a decreasing rate. However, geocement concretes showed 15–20% increase in strength from 28 to 90 days, compared to 3–8% for the Portland cement concretes. Grade 65 geocement concrete recorded 45% and 79% of its 28-day ambient cured strength after 4 and 24 h of heat-curing at 70 °C. Empirical relationships between heat-cured and 28-day ambient-cured strengths for geocement concretes are developed and could be used by precast industry for quality assurance purpose.

1. Introduction

Geopolymer binder sets and hardens with age at room temperature through the polymerization of aluminosilicate source materials (fly ash and slag) in the presence of alkaline activators. The polymerization process creates a tetrahedral chain of SiO_4 and AlO_4 by sharing the oxygen atoms alternatively [1,2]. The polymerization rate is slow at ambient temperature which attributes to the early age low compressive strength in geopolymer concrete [3,4]. Bonder et al. [5] reported that the effectiveness of powder form alkali activators is comparable with the solution form and is better than the granular form for natural pozzolan based geopolymers at 40 and 60 °C. The solubility of aluminosilicate compounds in alkaline solution is found to increase [5,6] with an increase in temperature and produces accelerated setting and hardening [7]. This consequently improves the early age strength in geopolymer concrete [8–10] and heat curing is recommended for geopolymer concrete.

Fly ash based geopolymer concrete is the most commonly used, even though its early age strength is low at ambient temperature. Addition of ground granulated blast furnace slag was reported to improve the compressive strength for fly ash based geopolymer concrete at all ages [11,12]. This is believed to be due to the coexistence of geopolymeric gel and calcium-silicate-hydrate (C-S-H) with slag and fly ash. The hydration reaction of

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cementitious slag, forming C-S-H gel, is responsible for the improvement in early age strength [4,13].

Similar to ordinary Portland cement, geocements set and harden at ambient temperature. However, the acceptance of geocement for structural concretes requires research into the understanding of the processes of setting and hardening at both ambient and accelerated curing conditions. The knowledge on the strength development under accelerated curing condition is needed by the pre-cast concrete production when geocement is used as the binder instead of Portland cement.

This paper reports the results of an experimental investigation into the development of compressive strength with age up to 90 days at ambient conditions for Grades 40, 50, 65 and 80 of geocement concretes. In addition, the effect of heat curing at 70 °C for either 4 h or 24 h on compressive strength of both geocement and Portland cement concrete were investigated.

2. Experimental investigation

2.1. Materials

Ordinary Portland cement (Type GP), complying with AS3972 [14], containing about 7% of limestone, was used to produce control concrete mixes. In geocement concrete mixtures, two types of geocement (Geocem GP and HE), consisting of low-calcium fly ash, ground granulated blast furnace slag and alkaline activators powder (a combination of sodium silicate, sodium hydroxide and other alkalis) were used. The fly ash and slag contents in Geocem GP were 70% and 30%, by weight and those in Geocem HE were 40% and 60%, respectively. The silicate modulus (molar ratio of SiO_2/Na_2O) and silica content (molar ratio of SiO_2/Al_2O_3) was 5.50 and 2.19 for Geocem GP and those for Geocem HE, were 5.05 and 2.36, respectively.

Table 1 shows the chemical compositions of the cement, fly ash and slag. The silica content of fly ash and slag was 48.3% and 32.9%, by weight, whereas the alumina content was 28.3% and 14.3%, respectively. The calcium content in the slag was 41.2%.

Crushed coarse river gravel, having the maximum aggregate size of 20 mm was used as coarse aggregates. A combination of medium and fine river sand was used as a fine aggregate. A high-range water-reducing admixture, complying with AS 1478.1 [15], was used in Portland cement concrete mixtures.

2.2. Mix compositions of concrete

The mix design of Portland cement concrete mixtures for Grades 40, 50, 65 and 80, having 100 mm slump, was carried out using DOE method of mix design [16]. The proportions of the mixtures were then modified to obtain mix proportions for the same grades of geocement concretes with similar consistency. Based on the experienced gained through preliminary investigation, the binder and water contents for geocement concrete mixtures were reduced by up to 30% from those required for Portland cement concrete mixtures. Table 2 summarises the compositions of the concrete mixtures with Portland cement and geocements.

2.3. Mixing and testing of fresh concrete properties

The concrete mixtures were producer in a rotating pan-type mixer, in accordance with the Australian Standard mixing procedure [17]. The freshly mixed concretes were tested using relevant Australian Standards for consistency [18], wet density [19] and setting time [20].

2.4. Casting of concrete specimens

For each concrete mix, a number of 100 mm diameter by 200 mm high cylinders was cast in standard steel moulds for the determination of compressive strength of concrete at various ages and different curing conditions. The fresh concrete in the cylindrical moulds was vibrated on a table vibrator to obtain full compaction. A minimum of three identical cylinders were tested in compression at any particular age and the mean compressive strength is reported.

2.5. Curing and testing of concrete specimens

On demoulding after 24 h of casting, Portland cement concrete cylinders were moist cured in lime saturated water at 23 °C until testing. The geocement concrete cylinders were sprayed with fresh water and sealed-cured at ambient temperature by wrapping with plastic sheets.

Similar to the accelerated curing regime adopted by the precast industry, the heat curing at 70 °C for 4 h was chosen in this investigation. Fig. 1 shows the temperature history for the heat-cured condition. For each concrete mix, six identical concrete cylinders in sealed moulds were subjected to heat curing after an initial delay period, depending on the concrete grade. The delay period was 90 min for Grades 40 and 50 concretes and 75 min for Grade 65 concretes. The rate of heating was 24 °C/h and the peak temperature was 70 °C. Three concrete cylinders were heat-cured for 4 h at 70 °C while the other three cylinders were heat-cured for 24 h. At the end of the heat-curing period, the cylinders were cooled in air for an hour, prior to testing in direct compression.

3. Results and discussion

3.1. Fresh concrete properties

Table 3 summarises the slump, wet density and final setting time for Portland cement and geocement concretes. The experience showed that the concrete mixtures were cohesive without any tendency to segregate under vibration, indicating proper mix design.

3.1.1. Water requirement and consistency of concrete mixes

The average slump (indicating the consistency of the mixture) for the Portland cement concrete mixtures was 100 mm, except one mixture with 200 mm. The water content of the mixtures varied from 150 to 179 kg/m^3, whereas the aggregate to binder ratio was ranged from 3.07 to 5.84, by weight.

Table 1
Chemical compositions of fly ash, slag and Portland cement.

	LOI*	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O	Others**
Fly Ash	1.74	3.97	48.3	28.3	11.8	1.51	0.22	0.41	0.60	2.64
Slag	0.36	41.2	32.9	14.3	0.47	5.42	2.4	0.22	0.33	0.85
GP	–	64.0	19.2	4.96	3.07	1.14	2.5	0.14	–	–

* LOI: loss of ignition.
** Combination of P_2O_5, TiO_2 and Mn_2O_3.