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Effect of sand, fly ash and limestone powder on preplaced aggregate concrete mechanical properties and reinforced beam shear capacity

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HIGHLIGHTS

- Effect of sand, fly ash and limestone powder in PAC grout is studied.
- Sand reduces flowability of PAC mixtures while fly ash compensates fluidity loss.
- Limestone powder does not significantly affect PAC grout fluidity.
- Replacing cement with limestone powder reduces mechanical strength.
- PAC members can be conservatively designed using current ACI 318 code provisions.

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ABSTRACT

A laboratory investigation on the effect of sand, fly ash, and limestone powder on mechanical properties of preplaced aggregate concrete (PAC) and shear strength of reinforced PAC beams without stirrups was conducted. Sand, fly ash and limestone powder is varied in each mixture to show their effects on the mechanical and structural strength properties of PAC. Ten reinforced PAC beams were cast, with PAC compressive strength ranging from 9.7 MPa to 35.8 MPa. From the same mix proportions, PAC slab members were cast to show an example application of PAC in the precast concrete industry. Beams were load tested in a four-point loading configuration with shear span to depth ratio (a/d) of 2.5, while slabs were loaded in equal 1/3 points. Load bearing performances of beams were evaluated based on load at first flexural cracking and ultimate shear load capacity. It was found that sand reduces workability of PAC grouts, but could be compensated by adding fly ash, while no significant fresh property effects were observed when cement was replaced with limestone powder. PAC mechanical strength had been shown to decrease as more cement was replaced with limestone powder. Modulus of rupture and ultimate shear strength of PAC beam members without stirrups can be designed using ACI 318-14 provisions. Finite element simulation using Vector2 can predict the ultimate shear strength of beam members. PAC example application through PAC slab members has shown similar performance at a lower concrete cost.

1. Introduction

PAC has a unique casting method where coarse aggregates are initially preplaced into the formworks. This allows more coarse aggregates to pack into formworks and interlock with each other, which is unique to that of conventionally cast concrete. This increase in coarse aggregate content on PAC could modify concrete behavior and properties. For example, the interlocking of coarse aggregate particles increases contact points of these particles [1]; which could better distribute stresses during loading [2]. Existing knowledge of conventional concrete should therefore be verified if they are still applicable for PAC. Basic properties of PAC should at least be known in order for the material to be properly utilized. Unfortunately, information in this regard is currently very limited.

Mechanical strength properties are widely used as a performance index of concrete. Apparently, several researches have already been done in this aspect [3–5]. It is interesting though that effects of limestone powder as cement replacement materials to reduce mixture cost has not been studied. This might be due to the grout workability limits imposed by the gravity injection method used [6], which caused honeycombing on stiff grout mixtures [7]. Thus, increasing powder content of mixtures through limestone fillers could further decrease grout workability or increase water demand [8]. But obviously, this matter should be studied further as limestone fillers have already been shown [9] to reduce mixture cost of high strength mortars without significant

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strength effects on low W/B mixtures. As for PAC grouts, which needs to be injected on the coarse aggregate media, should be fluid enough to fill all voids. Low W/B PAC grout mixtures though has been previously shown by Coo and Pheeraphan [10] to be injectable through a grouting pump. It was also shown in the same study that optimized PAC grout proportions with low W/B can attain high compressive strengths (>70 MPa on 150 mm cubic specimens) at a cost comparable to normal strength conventional concrete. The current study presents the possibility to reduce PAC material cost further by replacing cement with limestone powder. Further studies on the mechanical strength properties are done to better understand the material properties inherent to PAC.

Studies on the use of PAC on structural members are also limited, inadequate research data are available on the subject [11]. The limited amount of information, especially on the performance of structural members cast using PAC could impede the use of the material for structural purposes. The performance of PAC on actual structural members still needs further investigation in order to gain confidence in the use of the material.

This study addresses the mechanical and structural properties of PAC using common concrete making materials and environment in Southeast Asia. Attempting to provide better understanding and increase confidence in using the material for structural use.

2. Experimental program

2.1. Materials

Ordinary Portland Cement Type-1 (ASTM C150), locally sourced fly ash and limestone powder with specific gravity of 2.46 and 2.65 respectively, conforming to ASTM C618 as Type-F used as the binder and filler, respectively, throughout the experimental procedure. Particle size of limestone filler used is 30% retained on ASTM sieve #150 (70% passing through) and 40% retained on sieve #200 (60% passing through). Chemical composition of cement, fly ash, and limestone powder are shown in Table 1.

Natural river sand with fineness modulus and specific gravity of 2.41 and 2.65, respectively, is used throughout the study. Locally sourced crushed limestone was used as coarse aggregate with particle size range of 19 mm–25 mm and a fineness modulus of 7.72, complying with gradation standards of ACI 304, Grading 1 for PAC production.

The superplasticizer used is a polycarboxylate-based admixture with a specific gravity of 1.06 and 30% solid content, supplied in a transparent light brown liquid. All materials are stored in sealed plastic containers inside the laboratory with an ambient temperature of 30 ± 5 °C and 50 ± 5% relative humidity.

2.2. PAC mix proportion

Nine unique PAC mixtures with varying sand, fly ash, and limestone powder proportions are used to cast beam specimens and show their effects on the mechanical and structural properties of PAC, these are shown in Table 2. One specimen is duplicated to

Table 1
Chemical compositions of cement, fly ash and limestone powder used.

Chemical composition (%)	OPC type I (%)	Fly ash (%)	Limestone powder (%)
SiO_2	20.48	42.64	6.42
Al_2O_3	5.25	20.49	0.77
Fe_2O_3	3.82	11.48	0.26
CaO	65	14.27	54.9
MgO	0.95	2.62	2.36
K_2O	0.4	2.84	0.21
Na_2O	0.08	0.62	0.01
SO_3	1.9	2.22	0.33
LOI	1.89	0.63	34.23

Table 2
PAC mix proportions.

Beam/ Mix number	Mix code	Coded levels			Actual material ratios and weights per cubic meter PAC											
		Fly ash to binder	Sand to binder	Limestone powder to binder	Cement	Fly Ash		Sand		Limestone powder		Coarse aggregate	Water		Superplasticizer	
		FA/B	S/B	LP/B	kg/m^3	FA/B	kg/m^3	S/B	kg/m^3	LP/B	kg/m^3	kg/m^3	W/P	kg/m^3	SP%	kg/m^3
1	PF0S0L0	–1	–1	–1	689.7	0.0	0.0	0.0	0.0	0.0	0.0	1512.0	0.33	227.6	0.5	3.4
2	PF0S1L0.5	–1	1	1	212.8	0.0	0.0	1.0	425.6	0.5	212.8	1512.0	0.33	140.5	0.5	1.1
3	PF0S1L0	–1	1	–1	437.0	0.0	0.0	1.0	437.0	0.0	0.0	1512.0	0.33	144.2	0.5	2.2
4	PF0.4S0L0.5	1	–1	1	62.9	0.4	251.6	0.0	0.0	0.5	314.5	1512.0	0.33	207.5	0.5	1.6
5	PF0.4S0L0	1	–1	–1	392.4	0.4	261.6	0.0	0.0	0.0	0.0	1512.0	0.33	215.8	0.5	3.3
6	PF0.4S1L0.5	1	1	1	41.2	0.4	164.7	1.0	411.8	0.5	205.9	1512.0	0.33	135.9	0.5	1.0
7	PF0.2S0.5L0.25	0	0	0	283.6	0.2	103.1	0.5	257.8	0.3	128.9	1512.0	0.33	170.2	0.5	1.9
8	PF0.4S1L0	1	1	–1	253.4	0.4	168.9	1.0	422.4	0.0	0.0	1512.0	0.33	139.4	0.5	2.1
9	PF0.2S0.5L0.25	0	0	0	283.6	0.2	103.1	0.5	257.8	0.3	128.9	1512.0	0.33	170.2	0.5	1.9
11	PF0S0L0.5	–1	–1	1	330.9	0.0	0.0	0.0	0.0	0.5	330.9	1512.0	0.33	218.4	0.5	1.7