



Project Title: Better Utilisation of Ultimate Strength Gain of Concrete with Pozzolanic Materials for Sustainable Development of Construction Works in Hong Kong
Principal Investigator: Ir Prof. Albert Kwok-hung KWAN
Project ID: CICR/04/14
Research Institution: Hong Kong Concrete Institute
Subject Area: Environment and Sustainability

Objective

To study the strength development of concrete containing Supplementary Cementitious Materials (SCMs) of Pulverised Fuel Ash (PFA) and Ground Granulated Blastfurnace Slag (GGBS) with commonly adopted replacement percentages of 25% PFA, 35% PFA, 40% GGBS and 60% GGBS.

Background

Concrete is a mixture of Portland cement, sand, coarse aggregates and water. The principal cementitious material in concrete is Portland cement. Most concrete mixes produced for construction contain SCMs that make up a portion of the cementitious components in concrete. Some of these materials are called pozzolans, which by themselves do not have any cementitious properties, but when used with Portland cement, react to form cementitious compounds. Some examples of pozzolanic materials are PFA and GGBS.

The use of pozzolans in concrete has the following benefits: (i) attaining economic gain by using less cement, (ii) reducing the carbon footprint of concrete associated with the greenhouse gases emitted during Portland cement production, and (iii) increasing the strength and durability of the concrete produced.

Data and Methodology

1. Plant production test data (5,692 concrete cubes cast with different percentages of PFA and GGBS) were collected from seven local concrete batching plants. Data for concrete containing PFA were collected from six batching plants, whereas for concrete containing GGBS, only one concrete producer provided the data.
2. Laboratory compressive strength tests were carried out on concrete cubes containing 25% and 35% PFA, and 35% and 65% GGBS.
3. The above data were analysed to examine the ultimate strength gain of concrete.

Results and Findings

1. Analysis Based on Plant Production Data
 - (a) For concrete mixes containing 25% PFA, the average % strength increase from 28 days to 56 days is 10.5%.
 - (b) For concrete mixes containing 35% PFA, the average % strength increase from 28 days to 56 days is 13.2.
 - (c) For concrete mixes containing 40% and 60% GGBS, the average % strength increase from 28 days to 56 days is 11% and 13% respectively.



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2. Analysis Based on Laboratory Test Data

- (a) For concrete mixes containing 25% PFA, the average % strength increase at 56 days/90 days with respect to that at 28 days is 11.9%/18.2%.
- (b) For concrete mixes containing 35% PFA, the average % strength increase at 56 days/90 days with respect to that at 28 days is 15.7%/19.2%.
- (c) For concrete mixes containing 35% GGBS, the average % strength increase at 56 days/90 days with respect to that at 28 days is 6.4%/8.2%.
- (d) For concrete mixes containing 60% GGBS, the average % strength increase at 56 days/90 days with respect to that at 28 days is 9.6%/11.7%.

Recommendations

1. Concrete mixes containing at least 25% PFA or 60% GGBS will gain an increase in strength by more than 10% after 28 days, at which the contract compliance criteria for compressive strength are normally set. It is recommended to revise the compliance criteria for compressive strength of concrete given in the General Specification for Civil Engineering Works 2006, by one of the following ways:
 - (a) Extend the age, from 28 days to 56 days, for evaluation of compliance of compressive strength. Clause 16.59 (1) of the General Specification for Civil Engineering Works 2006 is proposed to be changed to:

Two test cubes shall be made from each sample of concrete taken as stated in Clause 16.58. Each pair of test cubes shall be tested to determine the compressive strength at 28 days except for designed mix concretes with at least 25% of PFA or 60% of GGBS in the total cementitious content, for which the test cubes shall be tested at 56 days.
 - (b) Increase the strength of concrete containing at least 25% PFA or 60% GGBS by 5%. To allow for variations in strength development of such concrete, a 5% increase in strength is proposed to be used. Clause 16.59 (5) of the General Specification for Civil Engineering Works 2006 is proposed to be changed to:

For the purpose of assessing compliance of designed mix concrete as stated in Clauses 16.61 and 16.62, the average of the two compressive strengths of the pair of test cubes shall be calculated and referred to as the test result. For designed mix concretes with at least 25% of PFA or 60% of GGBS in the total cementitious content, the test result can be multiplied by the factor of 1.05.
 - (c) Relax the requirement by 3 MPa in Column B of Table 16.10 of the General Specification for Civil Engineering Works 2006 for the C1 and C2 compliance criteria. The recommended criteria are marked C1b and C2b in Table 1 below.
2. It is also recommended that other organizations (e.g. HKHA, MTRC, AA and BD) consider to adopt the above recommendations.

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Table 1 – Revised Compliance Criteria for Compressive Strength of Designed Mix Concretes

Grade strength (MPa)	Containing at least 25% PFA or at least 60% GGBS in total cementitious content	Compliance criteria	Column A Maximum amount by which each test result may be below the grade strength (MPa)		Column B Minimum amount by which the average of any four consecutive test results shall be above the grade strength (MPa)	
			100mm cubes	150mm cubes	100mm cubes	150mm cubes
20 or greater	No	C1a	2	3	7	5
	Yes	C1b	2	3	4	2
	No	C2a	2	3	5	3
	Yes	C2b	2	3	2	0
Below 20	N/A	C3	2	2	3	2

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