Optimising concrete enhancement of local ready-mix concrete partially replaced with local fly-Ash

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Abstract. Concrete performance and workability can be improved by using an optimum amount of fly-ash. This leads to the purpose of analysing the percentage of fly-ash that can replace a certain amount of Portland cement in the concrete until it reaches the maximum strength. The experiment was conducted using G25 and G45 concrete supplied by a local ready-mix concrete plant in Kuching, Sarawak. The cement content of each concrete grade was replaced with various fly-ash percentages of 20, 30, 40, 50 and 60 collected from waste materials in Pending Sarawak. The specimens used in the studies were made of 150mm concrete cubes. Specimens were tested for compressive strength at the ages of 3, 7, 14, 28, 56 and 90 days. The curing age extended to 56th and 90th-day to participated slow pozzolonic reaction process contributed by fly-ash. Based on the test results for both concrete grades with enhancements, the compressive strength significantly increases from 7 days to 56 days, and then slightly increases on the 90th-day. The G25 concrete has an optimum strength with a fly-ash replacement of 30% cement content, followed by 40%, 20% and 50%. Similarly, the G45 concrete achieved an optimum strength with a fly-ash replacement about 30% cement content, followed by 20%, 40% and 50%. In addition, both grades of concrete tested have a cut-off cement replacement level of 60%, beyond which the compressive strength falls below that of the control mixtures.

1. Introduction
The initial economic cost of construction materials is the purchase price. This usually determines the decision on which material to use. Meanwhile, considerations on the durability and long term environmental effect are also playing main important role in the selection of construction material. Cement is the most widely used as construction material that is responsible for production of about
90% CO\textsubscript{2} as per its own production [1]. In which, One ton of Portland cement production discharges about 0.87 ton of greenhouse gas to the environment [2]. Besides, the major component of the OPC is naturally available, hence limited in terms of resources [1]. Therefore, the use of fly-ash in concrete can reduce the consumption of natural resources and also diminishes the effect of pollutant in the environment [1, 2, 3, 4, 5]. Recently, fly-ash is widely used to improve the durability of concrete through proceeded microstructural evolution by pozzolanic reaction during long-term hydration. High fineness mineral admixtures from fly-ash react with the product liberated at early ages during hydration to form a secondary C-S-H gel. In which, this gel is less dense and has more volume than primary C-S-H gel. All the pores inside the concrete were fully aquifer by the gels; hence the concrete provides high resistance to environmental deterioration. Chemically [6], secondary C-S-H gel produces as equation as follows;

\begin{equation}
C_3S + H \rightarrow C-S-H + Ca(OH)_2
\end{equation}

\begin{equation}
Ca(OH)_2 + S \rightarrow C-S-H
\end{equation}

Fly-ash is the notorious waste product of coal based electricity generating thermal power plants. It is finely divided residue, resulting from the combustion of ground or powdered coal and transported by the flue gases of boilers fired by the pulverized coal [7]. It is available in large quantities as a waste product from a thermal power and industrial plants [5, 7]. Locally, in Sarawak, there are at least three coal-fired power stations at the moment includes Mukah, Sejinkat and Balingian with total power supply generated up to 1080MW. As the matter of fact it is natural resources as the state holds nearly 70% of Malaysia’s coal reserve and Malaysian coal consumption are expected to reach 36 million tonnes in Year 2020. Therefore, it is a good time to utilise fly-ash as cement replacement material.

2. Research significance

In this study, compressive strength tests were carried out on 150 mm concrete cubes made of G25 and G45 concrete, at ages of 3, 7, 14, 28, 56 and 90 days. Then, similar tests were conducted on 150 mm concrete cubes made of G25 and G45 concrete, but the cement content of which had been replaced with various fly-ash percentages of 20, 30, 40, 50 and 60 by weight. Furthermore, the test results of optimum strength for both grades of concrete were verified by repeating the tests on the concrete with dominant percentages of fly-ash replacement at ages of 28 and 56 days.

3. Material and test methods

The concrete mixtures used are adopted from a previous study. The concrete mix design was provided by an established ready-mix concrete supplier in Kuching [8]. The G25 and G45 concrete mixtures were investigated for the optimum strength by replacing the cement content with fly-ash from 10% to 60%, with a 10% increment for each test. The designs of the concrete mix proportion are shown in Table 2. Fly-ash was collected from a power plant belonging to Sejingkat Power Corporation Sdn. Bhd., which is located in Pending, Sarawak, which has an annual coal consumption of up to 1 million tonnes [9]. Testing of the chemical composition was carried out using the gravimetric and atomic absorption spectroscopy [10]. The total amount of silicon dioxide (SiO\textsubscript{2}), aluminium oxide (Al\textsubscript{2}O\textsubscript{3}) and ferric oxide (Fe\textsubscript{2}O\textsubscript{3}) are exceeds 70%, which fulfil the criteria of Class F fly ash. In addition, the testing results for initial setting time and final setting time of fly-ash are summarised in Table 1. The compressive strength tests on the 150 mm cubes were conducted based on MS EN 12390-3:2012.
Table 1. Fly-Ash Properties.

| Chemical Composition (%) | Value | Physical properties | Value |
|--------------------------|-------|---------------------|-------|
| SiO$_2$                  | 58.8  | Initial setting time (min) | 125   |
| Al$_2$O$_3$              | 21.0  | Final setting time (min) | 325   |
| Fe$_2$O$_3$              | 7.4   |                     |       |

Table 2. Concrete Mix Proportions Design.

| Grade of concrete | Cement (kg/m$^3$) | Water/cement ratio | Fine Aggregate (kg/m$^3$) | Coarse Aggregate (kg/m$^3$) | Water (kg/m$^3$) | Slump (mm) |
|-------------------|-------------------|--------------------|---------------------------|----------------------------|------------------|------------|
| G25 (control)     | 320               | 0.55               | 809                       | 1020                       | 175              | 125        |
| G25FA20           | 256               | 0.52               | 809                       | 1020                       | 165              | 110        |
| G25FA30           | 224               | 0.50               | 809                       | 1020                       | 160              | 95         |
| G25FA40           | 192               | 0.50               | 809                       | 1020                       | 160              | 100        |
| G25FA50           | 160               | 0.48               | 809                       | 1020                       | 155              | 100        |
| G25FA60           | 128               | 0.48               | 809                       | 1020                       | 155              | 110        |
| G45 (Control)     | 422               | 0.35               | 621                       | 1284                       | 148              | 105        |
| G45FA20           | 338               | 0.35               | 621                       | 1284                       | 148              | 120        |
| G45FA30           | 295               | 0.33               | 621                       | 1284                       | 140              | 100        |
| G45FA40           | 253               | 0.27               | 621                       | 1284                       | 115              | 110        |
| G45FA50           | 211               | 0.24               | 621                       | 1284                       | 100              | 100        |
| G45FA60           | 169               | 0.24               | 621                       | 1284                       | 100              | 110        |

4. Results and discussion

The compressive strength results are summarized in Table 3 and Table 4 for concrete mixes enhanced by fly-ash on the concrete grades of G25 and G45 respectively. Each result calculated based on the average of three 150mm concrete cubes compression tests at same age of 3, 7, 14, 28, 56 and 90 days respectively.

Table 3. Mean Compressive Strength of Concrete Grade G25 with Various Percentages Fly-Ash Replacement.

| Percentages fly-ash replacement | DAY |
|---------------------------------|-----|
| 0%                              | 3   |
| 20%                             | 7   |
| 30%                             | 14  |
| 40%                             | 28  |
| 50%                             | 56  |
| 60%                             | 90  |

| DAY  | 0%  | 20% | 30% | 40% | 50% | 60% |
|------|-----|-----|-----|-----|-----|-----|
| 3    | 10.89 | 14.22 | 17.33 | 14.44 | 13.56 | 9.78 |
| 7    | 20.67 | 15.56 | 18.22 | 15.78 | 14.44 | 11.11 |
| 14   | 24.67 | 20.22 | 21.56 | 21.11 | 20.00 | 17.56 |
| 28   | 31.11 | 24.22 | 28.22 | 25.33 | 23.11 | 20.22 |
| 56   | 33.33 | 30.22 | 34.22 | 32.22 | 28.00 | 25.78 |
| 90   | 34.44 | 32.67 | 39.11 | 33.78 | 30.00 | 29.56 |
Table 4. Mean Compressive Strength of Concrete Grade G45 with Various Percentages Fly-Ash Replacement.

| Percentages fly-ash replacement | DAY  | 0%   | 20%  | 30%  | 40%  | 50%  | 60%  |
|--------------------------------|------|------|------|------|------|------|------|
|                                | 3    | 20.00| 30.44| 32.00| 27.11| 23.56| 24.89|
|                                | 7    | 34.89| 33.56| 34.89| 30.00| 25.78| 26.44|
|                                | 14   | 42.44| 44.67| 46.89| 42.67| 35.33| 27.33|
|                                | 28   | 50.44| 54.00| 56.44| 51.11| 45.56| 36.00|
|                                | 56   | 51.56| 59.56| 62.67| 58.00| 54.89| 48.67|
|                                | 90   | 52.22| 63.56| 67.78| 61.56| 57.33| 55.33|

4.1 Effect of fly ash on compressive strength of concrete with age

The compressive strengths of the different mixes in relation to the curing times for a particular percentage fly-ash replacement are shown in Figures 1 and Figure 2.

The Graph in Figure 1 shows that the control mixture of G25 develops the maximum amount of strength during the first 7 days. Then, the strength continues to increase moderately up to the 28th day before it plateaus in later days with almost negligible increase. All G25 concrete mixes enhanced by various percentages of fly-ash record low compressive strength development compared with the control mixture, up to the 28th day. Then the strength starts to increase uniformly and is higher than the control mixture during the periods of up to the 56th day and 90th day. The initial strength of the fly-ash concrete tends to be lower than that of the concrete without fly-ash due slow the pozzolanic reaction process [12]. In addition, based on the previous studies that investigated different percentages of fly-ash replacement in various grades of concrete, the maximum strength is only achieved at the age of 56 days or higher [4, 5, 7, 13]. According to the graph in Figure 1, the 30% replacement of fly-ash in the G25 concrete mixes develops the highest strength and this is followed by 40%, 20%, 50% and 60%. Similarly, results from previous study of G25 concrete with up to 30% fly-ash replacement show that the compressive strength is higher and almost equal to that of the control concrete mixture at the age of 56 days [14].

Besides, the compressive strength development for the G45 control concrete mixture is similar to the trend of G25 concrete. However, all concrete mixes enhanced with fly-ash record high strength development during the early period of up to the age of 28 days, compared with G25 concrete. Most of the enhanced concrete mixtures record higher compressive strength values compared with the control mixture at the age of 56 days, and far exceed that of the control specimen at the age of 90 days. Concrete develops strength at the later age, which may exceed the strength of the concrete without fly-ash due to continued pozzolanic reactivity [15]. Fly-ash is used in different grades of concrete mixtures with a distinct increment for the various replacement percentages and the results show increases in fineness volume and decreases in water content [16]. The graph in Figure 2 indicates that the optimum compressive strengths are developed with fly-ash replacements of 30%, followed by 20%, 40%, 50% and 60%.

Optimum strength for both concrete grades is similar to the finding from previous study. In which, replacement of even PPC cement with fly-ash is possible up to 30% [17]. Both graphs show that beyond the 30% replacement, the compressive strength decreases with an increase in fly-ash replacement at all the ages due to the voids in the concrete are fully filled with calcium silicate hydrate (C-S-H) gels. Mineral admixtures with high fineness react with the product liberated at the early ages during hydration, and form secondary C-S-H gel [15, 18]. This gel is less dense and has a higher
volume than the primary C-S-H gel. Therefore, it fills all the pores inside the concrete [1, 15]. Both graphs also indicate that the cut-off point of the cement fly-ash replacement is 60%, beyond which the compressive strengths will fall below that of the control mixtures.

Figure 1. Compressive strength against age of the specimen on G25 enhancement

![Compressive strength graph for G25 enhancement](image1)

Figure 2. Compressive strength against age of the specimen on G45 enhancement

![Compressive strength graph for G45 enhancement](image2)

4.2 Validation of optimised compressive strength enhanced by fly-ash

The optimum compressive strength was validated with additional concrete samples prepared with 30% fly-ash replacement for both G25 and G45 concrete. Prepared samples were tested for compressive strength simultaneously at the ages of 56 and 90 days. Compressive strengths of the prepared optimised samples were compared with the previous test results of compressive strength at the similar ages as shown in Table 5. Both grades of concrete show a range of errors from 9.67% to 10.40% and from 5.66% to 6.88% for G25 and G45 concrete respectively. Both ranges of error values are acceptable as recommended by [19, 11].
Table 5. Optimise Compressive Strength Validation for G25 and G45 with 30% Fly-ash Replacement.

| Grade | Sample No. | Age (days) | Current Compressive Strength (MPa) | Previous Mean Compressive Strength (MPa) | Error (%) |
|-------|------------|------------|-----------------------------------|-----------------------------------------|-----------|
|       |            |            | Value                             | Mean                                    |           |
| G25   | 1          | 2          | 38.22                             |                                         |           |
|       | 2          | 56         | 38.00                             | 37.78                                   | 10.40%    |
|       | 3          |            | 37.11                             |                                         |           |
|       | 1          | 90         | 42.22                             |                                         |           |
|       | 2          |            | 43.11                             | 42.89                                   | 9.67%     |
|       | 3          |            | 43.33                             |                                         |           |
| G45   | 1          |            | 62.22                             |                                         |           |
|       | 2          | 56         | 66.67                             | 66.22                                   | 5.66%     |
|       | 3          |            | 69.78                             |                                         |           |
|       | 1          |            | 72.00                             |                                         |           |
|       | 2          | 90         | 71.11                             | 72.44                                   | 6.88%     |
|       | 3          |            | 74.22                             |                                         |           |

5. Conclusion
The research findings of the effects of fly-ash on the compressive strength of the G25 and G45 concrete mixtures are as follows:

a. The optimum compressive strength of G25 concrete is achieved with fly-ash replacements of 30%, followed by 40%, 20%, 50% and 60%.

b. The optimum compressive strength of G25 concrete enhanced by 30% fly-ash replacement is only reachable at the age of 56 days.

c. The optimum compressive strength of G45 concrete is achieved with fly-ash replacements of 30%, followed by 20%, 40%, 50% and 60%.

d. The optimum compressive strengths of G45 concrete, enhanced with 20%, 30% and 40% fly-ash replacements, are reachable at the age of 28 days.

e. The cut-off point of cement fly-ash replacement is 60%.

f. The strength development of the concrete mixtures enhanced with fly-ash replacements becomes more pronounced at the later ages, i.e. 56 and 90 days.

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