KKU ENGINEERING JOURNAL 2016;43(S3):446-450 Research Article

KKU Engineering Journal

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# Development of high performance concrete containing high calcium fly ash

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Received April 2016
Accepted June 2016

**Abstract**

High performance concrete is a kind of concrete with compressive strength at 28 days over 50 MPa, high slump of 20 cm, and large flow of 50 cm without segregation. Low water to cement ratio is a usual practice to achieve the required high compressive strength. The amount of free water is decreased and often more cement is added into the system. However, Portland cement is relatively expensive and if used in large quantities, it can cause heat from reaction and fast setting of concrete, which lead to undesirable fresh concrete properties. This research is aimed to decrease the amount of cement and re-adjust mix proportion of high performance concrete to economize production cost and be able to use high performance concrete with the same quality.

In this research, the researcher re-adjusted the water to cement ratio to control slump and flow value to be more than 20 cm and 50 cm respectively. The test revealed that when 2.5% of super plasticizer by cement weight was added to the proportion, the compressive strength at 28 days reached 58 MPa with 30% cement reduction by weight. Moreover, when high calcium fly ash was mixed into the system, its work ability further improved, water to cement ratio decreased, and compressive strength increased. The result showed that it largely helped to decrease the use of cement and production cost, and the properties of high performance concrete remained satisfactory.

**Keywords:** High performance concrete, Mechanical properties, Fly ash, Workability

## 1. Introduction

Concrete is widely used in the construction industry, which leads to improvement of concrete properties and various types of concrete are produced to response to different property requirements. Most concrete users prefer a type of concrete that has high compressive strength after setting. It should also have great workability when it was a fresh concrete. This reason encourages the researcher to improve concrete to exhibit more efficient properties. In other words, the improvement should be done to achieve high compressive strength and great work ability in concrete. This type of concrete is called high performance concrete (HPC). Its main properties are as follows: compressive strength at 28 days greater than 50 MPa, water to binder ratio not more than 0.40[1] [2] , slump greater than 20 cm, and flow greater than 50 cm by compaction without segregation[3]. In the production of high performance concrete, large amount of fine aggregates are used [2]. Bouygues was the first to start research in Reactive Powder Concrete, a kind of Ultra-High Performance Concrete (UHPC) from 1990 to 1995. The preparation and performance of UHPC have been investigated in other literature [4]. However, the amount of cement used in mix proportion of the high performance concrete production is significant. It leads to high production costs. Therefore, the researcher interested in decreasing cement use by specifying slump, flow, and compressive strength at a value of greater than 20 cm, 50 cm, and 50 MPa respectively. This was done by adding super plasticizer and fly ash to gain more compressive strength and workability, so the amount of cement use could be decreased successfully.

## 2. Materials and methods

### *2.1 Materials and properties*

Crushed stone aggregate, river sand, Ordinary Portland cement Type I (OPC), and high calcium fly ash (FA) were used in this study. The chemical composition and physical properties of OPC and FA are shown in Table 1. Crushed stone aggregate was classified by 3/4" and 3/8" sieve size for using in mix proportion. The fine aggregate that used in mix proportion has fineness modulus (FM) of 1.49, specific gravity of 2.69, and water absorption of 0.43 %. The size distribution of fine aggregate is shown in Table 2. Both aggregates are prepared to achieve saturated surface dry before using.

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doi: 10.14456/kkuenj.2016.152

**Table 1** Chemical composition and physical properties of binders

| Chemical composition (%) | Portland Cement | Fly Ash |
|---|---|---|
| $SiO_2$ | 19.76 | 33.66 |
| $Al_2O_3$ | 9.01 | 18.25 |
| $Fe_2O_3$ | 3.48 | 16.35 |
| CaO | 61.20 | 19.23 |
| $Na_2O$ | - | 1.53 |
| $TiO_2$ | 0.41 | 0.35 |
| MgO | 2.02 | 2.84 |
| $K_2O$ | - | 2.08 |
| $P_2O_5$ | - | 0.17 |
| $SO_3$ | 2.31 | 2.74 |
| LOI | 1.38 | 0.10 |
| Density($g/cm^3$) | 3.12 | 2.21 |
| Fineness($cm^2/g$) | 3,100 | 2,700 |

**Table 2** The size distribution of fine aggregate

| Screen size | Cumulative sieve residue (%) |
|---|---|
| 4.75 | 0.00 |
| 2.36 | 1.58 |
| 1.18 | 3.36 |
| 0.6 | 7.82 |
| 0.3 | 42.23 |
| 0.15 | 94.98 |
| Tray | 100.00 |

*2.2 Coarse aggregate preparation*

Coarse aggregate is started by investigation to find the highest unit weight of 3/4" aggregate sieve size to 3/8" aggregate sieve size ratio. The investigation is done by assembling both sizes of aggregate according to the ratio in Table 3 and investigating unit weight according to ASTM C29. It revealed that the most suitable ratio of 3/4" aggregate sieve size to 3/8" aggregate sieve size is 60:40, which is used in the experiment.

**Table 3** The unit weight of coarse aggregate

| 3/4" (%) | 3/8" (%) | Unit weight ($kg/m^3$) |
|---|---|---|
| 100 | - | 1431.1 |
| 90 | 10 | 1653.2 |
| 80 | 20 | 1668.5 |
| 70 | 30 | 1681.5 |
| 60 | 40 | 1682.6 |
| 50 | 50 | 1675.0 |

*2.3 Concrete production*

The concrete mixture was done by collecting data from related research [5]. The researcher found that water to cement ratio was between 0.4-0.22 and 0.6 fine aggregate to coarse aggregate ratio was used. The mixture used in this experiment is in Table 4. It was divided into 4 series. Series 1 is a beginning series used to observe compressive strength and work ability and series 2 - series 4 are used to adjust water ratio to gain more than 20 cm of slump and 50 cm of flow to use as a control variable. Series 2 was to add SP into the system to find out suitable percentage of using SP to decrease water as much as possible. The aim was to gain the highest compressive strength of concrete. Series 3 continued from series 2 by implementing the highest percentage of SP to achieve the highest compressive strength in the mix proportion in series 3 and decreased the amount of Portland cement by omitting to adding fly ash. Series 4 was to reduce cement from 0 to 50 percent by weight and adding 15 percent of fly ash by cement weight.

*2.4 Testing*

Workability of fresh HPC, including slump and flow, was measured with a normal 30 cm. of slump cone in a laboratory with a temperature of (25 ± 3) C. in accordance to ASTM C143. The flow testing refers to the average diameter of the fresh concrete that spread after slump testing in accordance to ASTM C1611. A spread which was lower than 50 cm. means that the fresh concrete has no flow ability. Compressive strength was determined on the 100x200 mm. of (Cylinder) specimen at the ages of 1, 7 and 28 days in accordance to ASTM C39. After 24 hours, the fresh concrete was casting at the room temperature until the testing began. The results presented the average of three tested specimens.

## 3. Results and discussion

*3.1 Influence of w/c on workability and compressive strength*

Figure 1 and Figure 2 show that when water to cement ratio was at 0.29, the compressive strength would reach to 70 MPa, but the slump was lower than high performance concrete properties. 0.35 of water to cement ratio gave slump value as expected. It can be high performance concrete without adding super plasticizer. For the next testing, super plasticizer would be added, so 0.29 of water to cement ratio was chosen, because 0.35 of water to cement ratio liquidize fresh concrete too much. This was to achieve work ability by adding super plasticizer in the system.

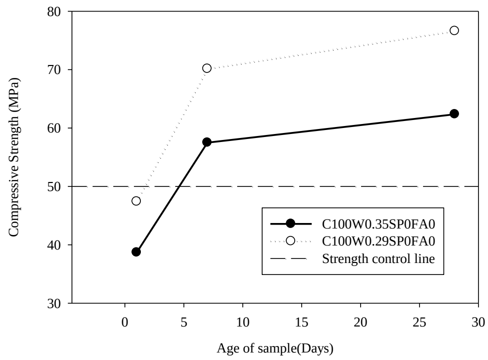


**Figure 1** Influence of w/c on compressive strength

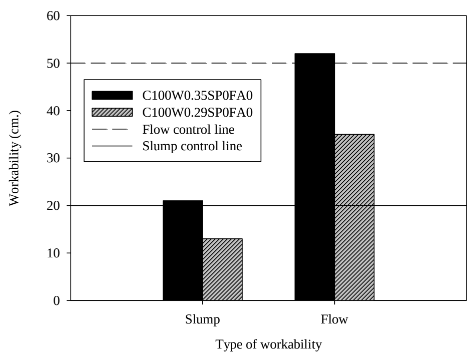


**Figure 2** Influence of w/c on workability

**Table 4** Mix proportions

| | W/C | Cement | Sand | Coarse aggregate 3/4 | Coarse aggregate 3/8 | Water | Superplasticizer | Fly Ash |
|---|---|---|---|---|---|---|---|---|
| | | | | | (kg/m$^3$) | | | |
| C100W0.35SP0FA0 | 0.35 | 580.00 | 590.00 | 588.00 | 392.00 | 203.00 | 0 | 0 |
| C100W0.29SP0FA0 | 0.29 | 580.00 | 590.00 | 588.00 | 392.00 | 168.20 | 0 | 0 |
| C100W0.29SP0FA0 | 0.29 | 580.00 | 590.00 | 588.00 | 392.00 | 168.20 | 0 | 0 |
| C100W0.29SP1.0FA0 | 0.29 | 580.00 | 590.00 | 588.00 | 392.00 | 168.20 | 5.80 | 0 |
| C100W0.29SP1.2FA0 | 0.29 | 580.00 | 590.00 | 588.00 | 392.00 | 168.20 | 7.00 | 0 |
| C100W0.26SP1.6FA0 | 0.26 | 580.00 | 590.00 | 588.00 | 392.00 | 150.80 | 9.30 | 0 |
| C100W0.24SP1.7FA0 | 0.24 | 580.00 | 590.00 | 588.00 | 392.00 | 139.20 | 9.86 | 0 |
| C100W0.22SP1.9FA0 | 0.22 | 580.00 | 590.00 | 588.00 | 392.00 | 127.60 | 11.02 | 0 |
| C100W0.24SP1.7FA0 | 0.24 | 522.00 | 590.00 | 588.00 | 392.00 | 125.28 | 8.87 | 0 |
| C90W0.25SP1.9FA0 | 0.25 | 522.00 | 590.00 | 588.00 | 392.00 | 130.50 | 9.92 | 0 |
| C80W0.26SP2.2FA0 | 0.26 | 464.00 | 590.00 | 588.00 | 392.00 | 120.64 | 10.21 | 0 |
| C70W0.29SP2.5FA0 | 0.29 | 406.00 | 590.00 | 588.00 | 392.00 | 117.74 | 10.15 | 0 |
| C60W0.32SP2.9FA0 | 0.32 | 348.00 | 590.00 | 588.00 | 392.00 | 111.36 | 10.09 | 0 |
| C50W0.35SP3.4FA0 | 0.35 | 290.00 | 590.00 | 588.00 | 392.00 | 101.50 | 9.86 | 0 |
| C100W0.23SP1.7FA15 | 0.23 | 580.00 | 590.00 | 588.00 | 392.00 | 133.40 | 9.86 | 87 |
| C90W0.24SP1.9FA15 | 0.24 | 522.00 | 590.00 | 588.00 | 392.00 | 125.28 | 9.92 | 78.3 |
| C80W0.24SP2.2FA15 | 0.24 | 464.00 | 590.00 | 588.00 | 392.00 | 111.36 | 10.21 | 69.6 |
| C70W0.26SP2.5FA15 | 0.26 | 406.00 | 590.00 | 588.00 | 392.00 | 105.56 | 10.15 | 60.9 |
| C60W0.30SP2.9FA15 | 0.30 | 348.00 | 590.00 | 588.00 | 392.00 | 104.40 | 10.09 | 52.2 |
| C50W0.33SP3.4FA15 | 0.33 | 290.00 | 590.00 | 588.00 | 392.00 | 95.70 | 9.86 | 43.5 |

*3.2 Influence of super plasticizer on workability and compressive strength*

From series 2 show in Figure 3 and Figure 4, when super plasticizer was added into the system, water to cement ratio could be decreased to lower than 0.29 to maintain slump and flow value as specified. From the experiment, compressive strength at 28 days age was lower after adding more than 1.7 % of super plasticizer into the system. When more than 1.7 % of super plasticizer was added, compressive strength was progressively lower. And when more than 1.9 % of super plasticizer was added into the system, the segregation occurred. When 1.7 % of super plasticizer was added, compressive strength reached to 80 MPa, which was 25% increased from control variable C100W0.29SP0FA0. Therefore, from mentioned reasons above, C100W0.24SP1.7FA0 testing kit was chosen to implement in the next step of this research to decrease the amount of Portland cement in series.

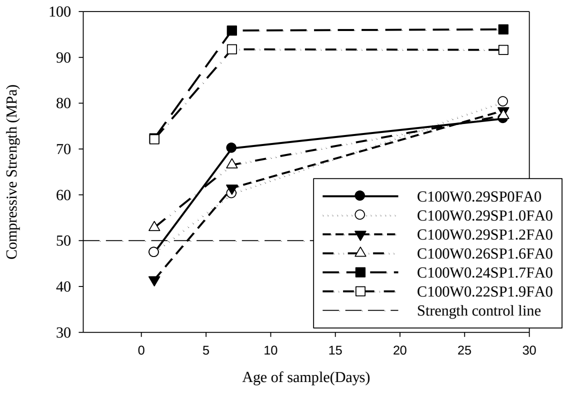


**Figure 3** Influence of SP on compressive strength

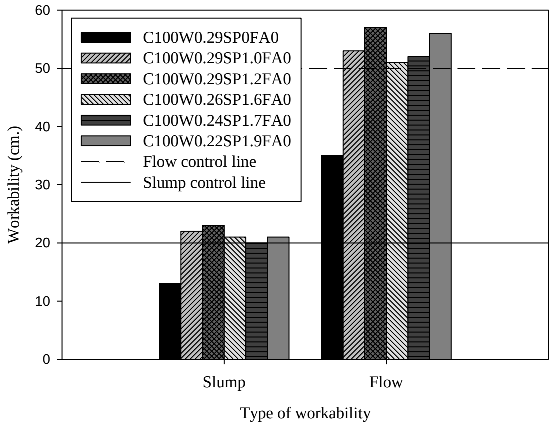


**Figure 4** Influence of SP on workability

*3.3 Influence of decreasing of Portland cement on workability and compressive strength*

Decreasing the amount of Portland cement leads to lower compressive strength because cement is a binder that holds particles together. From the testing, 30% of Portland cement could be decreased, while compressive strength and slump of fresh concrete was still in the criterion of high performance concrete, the result show in Figure 5 and Figure 6 . This could economize up to 170 kg/m$^3$ of cement. Decreasing large amount of cement caused greater total mass to cement ratio. If cement was decreased more than 30%, the concrete texture would be rough, segregation occurred, and super plasticizer could not be added into the system because the segregation between aggregate and mortar occurred clearly.

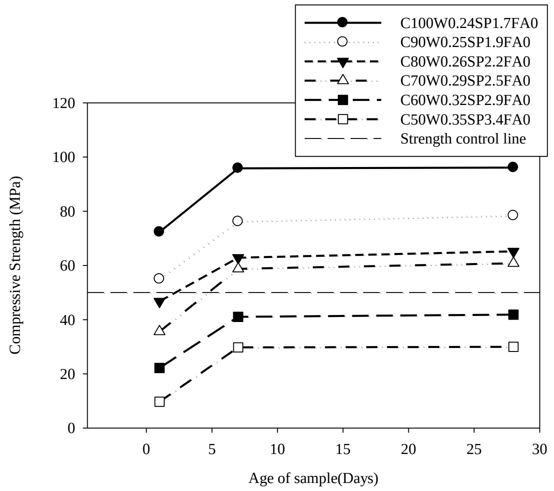


**Figure 5** Effect of Portland cement decreasing on compressive strength

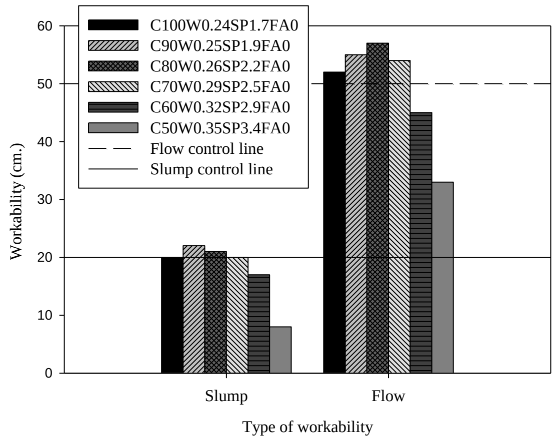


**Figure 6** Effect of Portland cement decreasing on work ability

*3.4 Influence of adding of fly ash on workability and compressive strength*

A great property of fly ash is that it helps to gain better work ability, because it's round and small particle[6] . The experiment result in showed that adding 15% of fly ash into the system with super plasticizer led to better work ability in high performance concrete and water to cement ratio could be decreased as shown in Figure 7. On the other hand, fly ash caused lower compressive strength in high performance concrete, which was affected by the pozzolanic reaction that occurred after hydration of Portland cement as seen in equation 1[7], because CaOH, a by-product of hydration reaction which was Calcium silicate hydrate (CSH)+ CaOH , was needed as seen in equation 2 [8]. The pozzolanic reaction gave CSH that helped to gain compressive strength after 28 days.

$$2\ Ca_3SiO_5 + 7\ H_2O \rightarrow 3\ CaO \cdot 2\ SiO_2 \cdot 4\ H_2O + 3\ Ca(OH)_2$$

equation 1

$$Ca(OH)_2 + H_4SiO_4 \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$$

equation 2

The Figure 7 and Figure 8 shows that 15% of fly ash could be decease cement to 40%, when the compressive strength of specimens reached up to more than 50 MPa that showed in Figure 9. This helped specimens to flow well and water to cement ratio could be decreased, which further led to 230 kg/m$^3$ of cement amount decreasing. From the calculation, 1m$^3$ concrete used 580kg/m$^3$. However, in the real usage, the user should be greatly careful, because when the amount of cement was decreased to 50%, high performance concrete properties would largely change in worse way. Furthermore, the segregation could be noticed as the amount of binder in those specimens was too low.

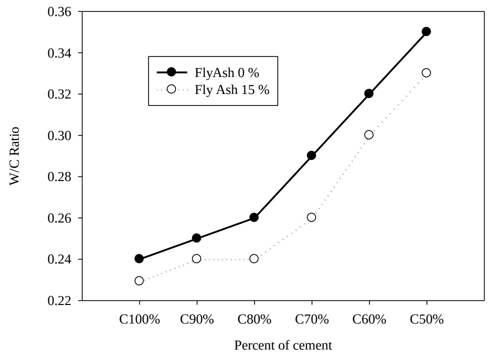


**Figure 7** Effect of water to cement ratio with 15% fly ash use

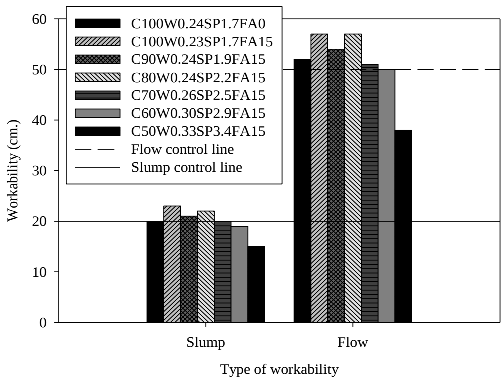


**Figure 8** Effect of Portland cement decreasing and 15% of fly ash adding on work ability

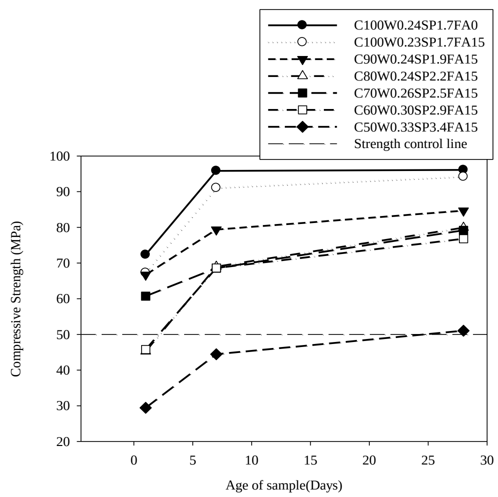


**Figure 9** Effect of Portland cement decreasing and 15% of fly ash adding on compressive strength

## 4. Conclusions

The experiment results reveals that high performance concrete can be produced without adding super plasticizer. However, water to cement ratio must be 0.35 to achieve 20 cm of flow. The most suitable amount of super plasticizer in this experiment is 1.7%. This leads to 58 MPa, the highest compressive strength and Portland cement can be decreased 30% or 170 $kg/m^3$ from 100% of cement or 580 $kg/m^3$. Fly ash can increase efficiency of work ability in high performance concrete and leads to decreasing of water to cement ratio. The Portland can be decreased 40% or 230 $kg/m^3$. This helps to produce efficient high performance concrete and economize production cost. In addition, the use of Portland cement, which its production causes harmful effects to environment, has been reduced.

## 5. Acknowledgements

This work was financially supported by Faculty of Engineering, Rajamangala University of technology ISAN Khon Kaen Campus.

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