The Properties of Self-Compacting Concrete Using Fly Ash from Hongsa Power Plant

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Abstract. This paper presents the investigation of properties of fresh and hardened concrete which combines of two cementitious materials, Ordinary Portland Cement (OPC) and Fly Ash (FA) from Hongsa Power Plant. The mixed proportion of concrete has been designed for 0.38 of water-binder ratio (w/p) and the replacement ratio of FA to OPC is 5% to 40% by mass which steps every 5% of FA. The total binders in the mixed proportion is 445kg/m³. The water reducing admixture which is Modified poly carboxylate type was used. The slump flow, T500, V-funnel and L-box were tested for investigation of the properties of fresh concrete. Then, compressive strength and tensile strength of concrete at 28 days of age were carried out for examining the hardened concrete properties. The results of study show that using cement combining with fly ash from Hongsa Power Plant improved the rheology of fresh concrete and the hardened concrete properties also have been improved dramatically.

Keywords: binders, Fly ash, cement, self-compacting concrete, fresh concrete, hardened concrete

1. Introduction
Self-compacting concrete (SCC) is the innovative concrete in modern era of concrete technology which is popular and widely uses in construction industry at the present time due to its multi-advantages comparing to conventional concrete. This kind of concrete is able to flow and compact without vibration and there is no segregation or bleeding when placing the concrete that reduces the consumption of the workforces [1]. Self-compacting concrete was initially developed since 1988 by Japanese engineers for solving the shortage of the labour and workmanship issues which creates defects in concrete leading to the declination of the quality and durability of the concrete consequently. The past thirty years have seen increasingly rapid development in RCC which is able to flow and fill in the formwork and the dense reinforcement without segregation. Due to high demand on the flow-ability of SCC, the important of its properties therefore depends on several factors, for instance, the quantities of aggregates, ratio of water to binders, and high range water reducing at mixture like Superplasticizer [2]. To increase the flow-ability of SCC without segregation and bleeding during the placing of concrete is the increasing of high volume of binders; especially, cement and the higher quantity of fine aggregate comparing to coarse aggregate and higher quantity of Superplasticizer [3]. These factors affect to the cost of SCC which is higher and conventional concrete; then, using of SCC is not popular due to its high cost. Therefore, the idea of reducing the quantity of cement is the highlight of the cost saving for SCC. The crucial options of reducing the quantity of cement is the adding of cement supplementary which are the bypass products such as rice husk ash, calcined natural pozzolan, ground granulated blast furnace slag and fly ash. These supplementary compounds are able to add before or during mixing the concrete [4,5,6]. Prajapati
Krishnapal et al. has carried out the research on SCC by adding fly ash as supplementary compound and found that the flowability and consistency especially the viscosity have been improved [7]. By the contrast, Sua-i-am et al. [6] found that the development of concrete strength depends on number of factors when using other powder as admixture especially fly ash. In this study, the properties of fresh and harden concrete which combines of two cementitious materials, Ordinary Portland Cement (OPC) and Fly Ash (FA) from Hongsa Power Plant were investigated in order to examine the properties of concrete when mixing with fly ash from Hongsa Thermal Power Plant which is local source in Lao PDR.

2. Experimental details
2.1 Materials and mix proportions
In this study, Ordinary Portland Cement (OPC) type I with specific gravity 3.15 and class F fly ash with specific gravity 1.78 from Hongsa Power Plant in Lao PDR were used as a binder materials. Table 1 shows the chemical composition of each binder, OPC and fly ash that used in the mix proportions. In addition, the river sand from Num Ngum with specific gravity of 2.38 and fineness modulus 2.60 was used as a fine aggregate. The crushed stone from Sakai Crushing Plant in Vientiane with specific gravity of 2.66, the nominal maximum size of 19mm was used as coarse aggregate. Table 2 shows the properties of coarse and fine aggregate that use in this study. The design of mix proportion of SCC in this study referred to ACI 237R-07 [9], ACI 211.1-91 [10], and EN 1992-1 [11]. The ratio of fine aggregate to coarse aggregate was fixed at 50:40 and the water powder ratio (w/p) is 0.38. Water reducing admixture, SikaPlast 257 which is Polycarboxylate ether or PCE based super-plasticizing and retarding with density of 1.12 kg/l, was mixed at 1.6% based upon the powder mass.

Table 1. Chemical composition and fineness of cement and fly ash from Hongsa Power Plant

| Material                  | Chemical composition (mass %) | Blaine fineness (cm²/g) |
|---------------------------|-------------------------------|-----------------------|
|                           | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | SO₃ | Free lime | OPC, Type I | 19.7 | 5.19 | 3.34 | 64.8 | 2.54 | 0.87 | 3100 |
|                           |      |       |       |     |     |          | Fly ash (from Hongsa) | 44.21 | 31.85 | 6.20 | 6.01 | 0.53 | 0.45 | 1730 |

Table 2. Properties of aggregates

| Aggregates | Loose Unit weight (g/cm³) | Absorption (%) | Specific gravity | Los Angeles | Flakiness Index | F.M |
|------------|--------------------------|----------------|------------------|-------------|-----------------|-----|
| Coarse aggregate | 1.36 | 0.6 | 2.66 | 22.35 | 41.43 | - |
| Fine aggregate | 1.55 | 1.42 | 2.38 | - | - | 2.6 |

Table 3. Mix proportion of concrete in this study

| Designation of mixed proportion (Mixed ID) | Fly ash content (%) | W | C | FA | F | CA | AE |
|------------------------------------------|---------------------|---|---|----|---|----|----|
| SCF0                                     | 0                   | 191| 445| 45 | 752| 730| 7.12|
| SCF5                                     | 5                   | 191| 423| 22 | 752| 730| 7.12|
| SCF10                                    | 10                  | 191| 401| 45 | 752| 730| 7.12|
| SCF15                                    | 15                  | 191| 378| 67 | 752| 730| 7.12|
| SCF20                                    | 20                  | 191| 356| 89 | 752| 730| 7.12|
| SCF25                                    | 25                  | 191| 334| 111| 752| 730| 7.12|
| SCF30                                    | 30                  | 191| 312| 134| 752| 730| 7.12|
| SCF35                                    | 35                  | 191| 289| 156| 752| 730| 7.12|
| SCF40                                    | 40                  | 191| 267| 178| 752| 730| 7.12|

W: water, C: cement, FA: fly ash, F: fine aggregate, CA: coarse aggregate, AE: water reducing admixture
After designing of standard reference sample, SCF0 for a cubic meter with 0% of fly ash and 445 kg of cement, then the quantities of aggregates, water, and admixture were fixed. The replacement ratio of fly ash to cement has substituted that starts from 5% to 40% by mass which stepped every 5% of fly ash. The replacement percentage of fly ash to cement by mass are 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, and 40% which refer to mix ID sample SCF0, SCF5, SCF10, SCF15, SCF20, SCF25, SCF30, SCF35, and SCF40 respectively; the details summary of all mix proportions in this study are shown in Table 1, there are nine mixes totally.

2.2 Sample preparation and Testing method
There are several parameters to be tested for investigating the workability of RCC fresh concrete. Following the guidelines of the European Federation of Specialist Construction Chemicals and Concrete Systems that established in 2002 on EFNARC Specification and Guidelines for Self-Compacting Concrete, the test parameters and specification for fresh concrete show in Table 4 have been carried out for all mix proportions. The workability of RCC depends on flow-ability, filling ability, passing ability, and segregation resistance. The test for verifying the filling ability is slump flow and T500 which evaluate the flow-ability and flow rate of RCC. In additions, V-funnel and L-box are used for evaluate the passing ability of RCC, these test is use for measuring the quantity of concrete through the narrow channel with specific of time as indicated in Table 4. Similarly, V-funnel at 5 minutes test is not only to evaluate passing ability, but also to evaluate the segregation resistance of SCC at the time of flowing as well. Figure 1a.) to 1e.) illustrate the testing set up and results of experiment at laboratory for each testing parameter, slump flow, T500 Slump flow, V-Funnel, V-Funnel at 5 min., and L-box respectively.

Table 4. The guidance of EFNARC for measuring the fresh properties of self-compacting concrete [8]

| NO | Method                  | Unit | Typical range of Values |
|----|-------------------------|------|-------------------------|
| 1  | Slump flow              | mm   | 650 - 800               |
| 2  | T500 Slump flow         | sec  | 2 - 5                   |
| 3  | V-funnel                | sec  | 6 - 12                  |
| 4  | V-funnel at 5 minutes   | sec  | 6 - 15                  |
| 5  | L-box                   | (h2/h1)| 0.8 - 1.0              |

Figure 1. Fresh concrete testing illustration

For harden concrete, compressive strength and tensile strength test were conducted at 28-days of age under water curing in room temperature condition. The cylinder specimen with diameter of 100mm and height 200mm were prepared. The total numbers of specimen is 25 samples were prepared for compressive strength test which follows ASTM C39 [25]. For the tensile strength test, the slitting test was employed to determine the tensile strength of harden concrete that follow ASTM D638 [26].
3. Results and Discussion

3.1 Effect of fly ash to properties of fresh concrete

In this study, the slump flow of fresh concrete conforms to specification of RCC which recommend by The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC), shows in Table 4, the slump flow of all mix proportion is between 650mm to 800mm as shown the results of slump flow in Figure 2. These results show that, the slump flow increase when the percentage of fly ash increase up to 10%, then. After 10% of fly ash, the slump flow slightly decrease, but it is over 650mm which is the minimum requirement of the RCC. The reason of slump flow decrease after 10% of fly ash is due to the water consumption of fly ash from Hongsa Power Plant is 103% that is greater than OPC by 3%, while water in the all proportions was fixed at 191kg. Therefore, when amount of fly ash in the mixture component of concrete increase, the water demand is increase, then, slump flow decrease. These tendency conforms to previous research that carried out by Jaturapitakkul et al. [12] and the manual of concrete practice that established by ACI [13]. However, even the slump flow decreases when percentage of fly ash equal or larger than 15% but the flow distance almost the same. By comparing the 0% of fly ash and 40% of fly ash which is the highest fly ash content, the slump flow decreased only 9.3% and it is still larger than the specification requirement.

![Figure 2. Slump flow measurement result](image)

Similarly, for T500 slump flow test which measure the speed of the flow for determining the filling ability of RCC, the results show that, the fly ash increase, the viscosity of fresh concrete also increase resulting of increasing of flowing time of free flow for T500 as shown in Figure 3, the time of flowing for T500 testing that presented by EFNARC [8] shall be limited in between 2 to 5 second. The flow rate was maintained in the specification when the fly ash is lower smaller than 30%. On the other hand, when percentage of fly ash equal or larger than 30%, the flow rate is slow and it is over standard requirement due to its higher viscosity. In the same way, the results of V-funnel and V-funnel at 5 min. test presented in Figure 4 and Figure 5 show that when fly ash content increase, the flow rate decrease, it take longer time to flow but no segregation were found in the test. The fly ash content equal or larger than 30% the flow rate is decrease and it is out of range of the standard requirement which is limited to 6-12 sec. for V-funnel and 6-15 sec. for V-funnel at 5min. respectively; same tendency of T500 and slump flow results.

![Figure 3. T500 measurement result](image)

![Figure 4. V-funnel measurement result](image)
The L-box test results presented in Figure 6 also share the same tendency with other fresh concrete test results as explained above. The L-box measurement was test to check the passing ability of fresh concrete while placing in the formwork with congested by reinforcement. This test lets concrete flow via the channel with vertical reinforcing bars where the concrete was placed, then the differential height of concrete at the placing location \( h_1 \) and at the end of box \( h_2 \) was measured to compare the leveling of concrete surface, the ratio of \( h_2/h_1 \) was calculated. The results show that when the fly ash content equal or greater than 30% the ratio of \( h_2/h_1 \) is out of range of the standard requirement. That means the ability of flowing of fresh concrete via the obstructed object was decreased due to its high viscosity.

From the above results of fresh concrete testing, the flow-ability and filling ability show a well relations that when fly ash content equal or larger than 30%, the flow rate has been decreased resulting the out of range of the standard specific requirement. However, the free flow test, slump flow testing, is still remain in the range of requirement that is considering for practical purpose use is still promising.

### 3.2 Effect of fly ash to properties of harden concrete

The compressive strength test result of harden concrete samples at 28-days for cylinder specimen have been presented in Figure 7. The compressive strength gradually increase when the percentage of fly ash increase up to 15%. The compressive strength is almost constant between fly ash content 15% to 30%, then slightly decrease at 35% and 40% of fly ash content mixture. The highest compressive strength of all mix proportions is 60.11 MPa with the supplementary percentage of fly ash to cement is at 20%; by comparison, the compressive strength increases 13.4% compare with standard reference sample which no-adding fly ash sample (0% of fly ash), 53.89MPa. The differences of compressive strength of the highest fly ash content mix proportion (40%) and no fly ash content mix proportion (0%) which is standard reference sample is only 3.4%, that is 53.89 Mpa for 0% fly ash content and 55.74 Mpa for 40% fly ash content. By overall, the compressive strength of harden concrete after adding fly ash has been improved compare to non-fly ash proportion.

![Figure 7. Compressive strength test result for 28-day of age](image-url)
For tensile strength test results that presented in Figure 8, when the fly ash content increase, the tensile strength is gradually increase. However, the strength of mix proportion of 0% to 20% fly ash content is develop larger than 25% to 40%, by comparing 0% and 25% of fly ash content, the increasing of tensile strength is 40.92% while the increasing of tensile strength of 25% to 40% of fly ash content is only 3.27%. These tendency show that the strength development of concrete is largely depend on the amount of cement at the early stage. Based on the previous research, the strength of concrete mixed with fly ash will continue to develop the strength between 1-6 months [14]. The main chemical element in cement that contributes to strength development in a short term is $3\text{CaO}.\text{SiO}_2$ ($\text{C}_3\text{S}$) and long term is $2\text{CaO}.\text{SiO}_2$. However, when fly ash was added to concrete as admixture, the pores in concrete was filled by fly ash particles at the early age resulting to densify inside the concrete [15,16].

![Figure 8. Tensile strength test result for 28-day of age](image)

4. Conclusion

In this study, the properties of self-compacting concrete using fly ash from Hongsa Power Plant have been investigated. The conclusions derived from this study for both fresh and harden concrete properties are summarized as follows:

1. The flow-ability of fresh concrete conforms to the standard of self-compacting concrete specification which presented by the European Federation of Specialist Construction Chemicals and Concrete Systems, the slump flow is between 650mm to 800mm for all mix proportions even the fly ash increases up to 40%.
2. The passing ability of fresh concrete decreases when the supplementary percentage of fly ash increase, the percentage of fly that make the passing ability conforms to standard is up to 25%; after 25% of fly ash, the passing ability is reduced due to high viscosity in fresh concrete.
3. The highest compressive strength of all harden concrete mix proportions is SCF20, 60.11 MPa, that supplementary percentage of fly ash to cement is 20%; the compressive strength increases 13.4% comparing to standard reference sample which non-adding fly ash sample SCF0, 53.89MPa. The compressive strength of the highest supplementary percentage of fly ash to cement 40%, SCF40 is 55.74MPa which maintains at higher than standard reference sample SCF0, 53.89MPa by 3.4%.
4. The results of study show that using cement combining with fly ash from Hongsa Power Plant improved the rheology of fresh concrete and the hardened concrete properties also have been improved dramatically.
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