Utilization of Local Fly Ash for Producing Self-Compacting Concrete

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Abstract. Self-compacting concrete (SCC) mixture is an innovation that aimed to ease concrete casting due to its characteristic can be compacted by self-weight without compacting or vibrating. The original SCC mixture which first developed by Okamura contains silica fume (SF) as supplementary material. In this study, fly ash (FA) was used as supplementary cementitious material for SF substitute. The variation of FA used in the mixtures of SCC concrete was 10%, 15%, and 20% by cement weight. For all variations of FA, the results of fresh concrete tests obtained workability that satisfactory to the SCC criteria for the slump flow, V-funnel, and L-shaped box tests. Furthermore, the results of hardened concrete tests achieved the compressive strength ranging from 40 to 46 MPa. These results indicate that local Aceh FA originating from Nagan Raya can be used as supplementary cementitious material to produce SCC with the compressive strength lay in high strength concrete categories.

1. Introduction
The development of science and technology in the construction project has new findings annually as like in designs or construction methods. The concrete casting in the civil construction for reinforced concrete structural elements necessary compacting or vibrating work. This compacting work aims to remove large air voids that developed during fresh concrete placement and to ensure the concrete has filled to all the corners of formwork.

In some field cases, there were often found that the distance between reinforcement bars relatively narrow, so that was difficult to do well compacting which result in honeycombing and unfilled cavities, including both surface and hidden voids (Figure 1). Finally, incomplete compacting will occur decreasing concrete durability. As a solution, in Japan in 1986, Okamura succeeded in developing self-compacting concrete (SCC) which is a concrete capable of compacting itself. Unlike conventional concrete, SCC does not require compacting using an external compactor or mechanical equipment such as a vibrator [1].

Regarding composition, compared to conventional concrete, SCC consists of a large number of binders, super-plasticizers, and/or viscosity modifying admixtures (VMA), and fillers in the form of fine and coarse aggregates (Figure 2). Other than cement, the binder used consists of supplementary cementitious material (SCM) such as fly ash (FA), slag furnace slag (GGBFS), silica fume (SF), metakaolin (MK), and rice husk ash (RHA) [2].
The use of SCM materials combination with cement provides many benefits to fresh and hardened concrete, including increased workability and high compressive strength. The SCM materials also provide cost-effective to concrete mixtures considering SCM can replace up to 40% of cement weight [3].

As described by Sfikas [3], when SCC used in civil construction, it can provide several benefits, including:

- Good rheological properties, SCC can flow to complicated mold corners,
- Faster casting, reduced equipment and few workers employed,
- Mechanical properties that are generally equivalent to conventional concrete or better, and increase durability,
- High aesthetics, with a perfect finish, free from defects,
- Increased health of environment work/noise reduction, due to it does not use a mechanical vibrator.

Siddique [4] reported that SCC made with SCM of FA Class F ranging from 15% to 35% of cement mass, produces compressive strengths of 29 MPa to 35 MPa at 28 days concrete age, and slump flow of fresh concrete ranges from 600 - 700 mm. From a durability test result, the mixture of SCC made with FA showed high chloride impermeability resistance.

In this study, FA was used as SCM for SF substitute. The local FA used from the waste of the Steam Power Plant in Nagan Raya Regency, Aceh Province, Indonesia. Based on the characterization of the Nagan Raya FA by Melisa [5], it was found that the content of SiO₂ (41.51%), Al₂O₃ (17.67%) and Fe₂O₃ (10.72%), total of these three compounds are 69.9%; thus this SCM can be categorized as FA class F according to ASTM C 618-03 [6]. The variation of Nagan Raya FA used for producing SCC in this study was 10%, 15%, and 20% of cement mass.

2. Materials and methods

2.1. Materials

Portland composite cement (PCC) by PT. Semen Padang, Indonesia is used as the main binder. The fine and coarse aggregates are river sand and crushed stone respectively, both of them was delivered from Krueng Mane, North Aceh Regency, Indonesia, and them sieving analysis is shown in Table 1.

Modified polycarboxylate super-plasticizer (SP) type of Sika® ViscoCrete®-8045P by PT. Sika Indonesia was used as a chemical admixture in SCC mixtures. Water for concrete mixture was obtained from the Laboratory of Civil Engineering Department, Universitas Malikussaleh. The SCM material of FA was carried from Nagan Raya with chemical compounds as shown in Table 2. Furthermore, the properties of the materials used for producing SCC are presented in Table 3.
### Table 1. Sieving analysis of aggregates

| Sieve size (mm) | % Pass | Sand | Crushed stone |
|-----------------|--------|------|---------------|
| 12,50           | 100    | 100  |               |
| 9,50            | 100    |      | 53,15         |
| 4,75            | 100    |      | 3,30          |
| 2,36            | 99,90  |      | 0             |
| 1,18            | 82,80  |      | 0             |
| 0,60            | 49,50  |      | 0             |
| 0,30            | 23,60  |      | 0             |
| 0,15            | 1,80   |      | 0             |
| Fine Modulus    | 2,42   |      |               |

### Table 2. Chemical compounds of Nagan Raya fly ash

| Compounds | % wt. | Compounds | % wt. |
|-----------|-------|-----------|-------|
| SiO₂      | 41,51 | K₂O       | 1,36  |
| Al₂O₃     | 17,67 | TiO₂      | 0,61  |
| Fe₂O₃     | 10,72 | P₂O₅      | 0,32  |
| CaO       | 8,50  | Na₂O      | 0,42  |
| MgO       | 3,36  |           |       |

Source: Melisa [5]

### Table 3. Material properties

| Description               | Sand | Crushed stone | Cement | FA     | SP     |
|---------------------------|------|---------------|--------|--------|--------|
| Maximum size (mm)         | 4,75 | 12,00         | -      | -      | -      |
| Specific gravity Saturated surface dry | 2,69 | 2,62         | 3,12   | 2,31   | 1,06   |
| Specific gravity Oven dry | 2,67 | 2,56         |        |        |        |
| Absorption (%)            | 1,25 | 2,26         | -      | -      | -      |
| Moisture content (%)      | 1,95 | 0,90         | -      | -      | -      |

2.2. Fly ash preparation

Original fly ash taken from Nagan Raya was sieved to pass sieving no. 200 (75 μm) (Figure 3), then oven with a stable temperature of 200°C for ± 24 hours, to get oven dry FA.

2.3. Mixtures composition and specimens preparation

The SCC mix design in this study was guided by the ACI 237R-07 [7] and ACI 211.4R-08 [8]. The FA was set of 10%, 15%, and 20% by cement weight. Iron cylinders with a diameter of 100 mm and a height of 200 mm was used as fresh concrete molds. From the SCC mix design, the water-binder ratio (w/b) was 0.389 (target compressive strength: 50 MPa) and the material proportion for each concrete variant is shown in Table 4.
The laboratory drum mixer was used for mixing SCC material. The mixing sequences is showing in Figure 4.

The mixing was stopped after the material mixed well and looks homogeneous which can be identified based on the color of the mixture has been entirely the same. Then the fresh SCC characteristics were executed and as soon as possible poured into an iron cylinder mold.

2.4. Testing of fresh SCC characteristic
According to the European Federation of National Associations for Representing for Concrete [9], there are 10 (ten) methods that can be used for testing of fresh SCC characteristics and them divided into 3 (three) basic categories, namely filling ability, passing ability, and segregation resistance as shown in Table 5. In this study, only 4 (four) tests were conducted on fresh SCC, namely Slump-flow by Abrams cone, \( T_{50cm} \) slump flow, V-funnel, and L-box. The criteria for each test are based on the values presented in Table 6.

### Table 4. Material proportion

| No. | Sample | FA % | Target slump flow | Material proportion per m\(^3\) (kg) |
|-----|--------|------|-------------------|-------------------------------------|
| 1   | SCC10  | 10   |                   | Cement 518.96 192.90 860.14 711.46 51.93 22.17 |
| 2   | SCC15  | 15   | 550 mm            | Cement 497.20 189.91 860.14 711.46 74.83 21.12 |
| 3   | SCC20  | 20   |                   | Cement 478.56 186.92 860.14 711.46 95.75 21.12 |

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### Table 5. Methods for testing of fresh SCC characteristics

| No. | Methods                   | Properties         |
|-----|---------------------------|--------------------|
| 1   | Slump-flow by Abrams cone | Filling ability    |
| 2   | \( T_{50cm} \) slump flow | Filling ability    |
| 3   | J-ring                    | Passing ability    |
| 4   | V-funnel                  | Filling ability    |
| 5   | V-funnel at \( T_5 \) minutes | Segregation resistance |
| 6   | L-box                     | Passing ability    |
| 7   | U-box                     | Passing ability    |
| 8   | Fill-box                  | Passing ability    |
| 9   | GTM screen stability test | Segregation resistance |
| 10  | Orimet                    | Filling ability    |

Source: EFNARC [9]
Table 6. Acceptance criteria for self-compacting concrete

| No. | Methods                      | Apparatus dimensions | Unit | Typical range of values | Min | Max |
|-----|------------------------------|----------------------|------|-------------------------|-----|-----|
| 1   | slump flow by Abrams cone   | Figure 5a            | mm   | 450 - 760               |     |     |
| 2   | T_{50cm} Slump flow          |                      | sec  | 2 - 5                   |     |     |
| 3   | V-funnel (Viscosity Class 2) | Figure 5b            | sec  | 9 - 25                  |     |     |
| 4   | L-box                        | Figure 5c            | (h_2/h_1) | 0.8 - 1.0  |     |     |

Source: ACI 237R-07 [7], * EFNARC [9]

2.5. Sample curing and testing of hardened SCC
After casting in a cylindrical mold, the specimen was wrapped with clear plastic. One day later, the mold was removed and the specimen immersed in water. Cylindrical specimens were tested according to ASTM C 39/C 39M [10] standard at the concrete age of 28 days.

Figure 5. Basic dimensions of SCC apparatus
a) Abrams cone, b) V-funnel, c) L-box
Source: Schutter [11]
3. Results and Discussion

3.1. Fresh SCC characteristic

The results of fresh SCC characteristic testing of all fly ash variations are shown in Table 7. This table shows the slump-flow by Abrams cone, T50cm slump flow, V-funnel, and L-box. On the slump-flow tests (Figure 6a), all SCC variants show the slump-flow which confirmed to the standard in the range of 595 – 643 mm, larger than the target slump flow of 550 mm, and was an indication of good rheology with a T50cm slump flow is 3 – 5 seconds. Similarly, the V-funnel test (Figure 6b), all SCC show the value of time flow in the range of 13 – 21 seconds. Furthermore, the L-box test (Figure 6c) achieved the ratio of h1 and h2 in the range of 0.85 – 0.99. The overall of fresh SCC characteristics testing meet the criteria set out by ACI 237R-07 [7] and the EFNARC [9].

![Figure 6. Fresh SCC characteristics test](image)

(a) Slump flow test, b) V-funnel test, c) L-box test

### Table 7. Characteristics of fresh SCC

| No. | Sample | Characteristics test | Slump-flow (mm) | T50cm slump flow (sec) | V-funnel (mm) | L-Shape h1/h2 |
|-----|--------|----------------------|----------------|------------------------|---------------|---------------|
| 1   | SCC10  | 643                  | 3             | 14                     | 0,989         |
| 2   | SCC15  | 612                  | 4             | 16                     | 0,853         |
| 3   | SCC20  | 595                  | 5             | 20                     | 0,836         |

### Table 8. Compressive strength of SCC samples

| No. | Sample | Load (kN) | Cylindrical specimens compressive strength (MPa) | Standard Deviation |
|-----|--------|-----------|------------------------------------------------|-------------------|
|     |        |           | Size. 100 mm | Ratio | Size. 150 mm | Average |               |
| 1   | SCC10  | 300       | 38,20         |       | 36,75       | 40,66   | 2,79          |
| 2   | SCC10  | 320       | 40,74         |       | 39,19       |         |               |
| 3   | SCC15  | 340       | 43,29         | 0,962 | 41,64       |         |               |
| 4   | SCC15  | 340       | 43,29         | 0,962 | 41,64       |         |               |
| 5   | SCC20  | 360       | 45,84         |       | 44,10       |         |               |
| 1   | SCC15  | 360       | 45,84         |       | 44,10       |         |               |
| 2   | SCC15  | 360       | 45,85         |       | 44,10       |         |               |
| 3   | SCC15  | 370       | 47,11         | 0,962 | 45,32       | 45,20   | 1,09          |
| 4   | SCC15  | 375       | 47,75         |       | 45,94       |         |               |
| 5   | SCC20  | 380       | 48,38         |       | 46,54       |         |               |
| 1   | SCC20  | 360       | 45,84         |       | 44,10       |         |               |
| 2   | SCC20  | 365       | 46,47         |       | 44,70       |         |               |
| 3   | SCC20  | 380       | 48,38         | 0,962 | 46,54       | 46,79   | 2,47          |
| 4   | SCC20  | 400       | 50,93         |       | 48,99       |         |               |
| 5   | SCC20  | 405       | 51,57         |       | 49,61       |         |               |
3.2. **Compressive strength**

The average compressive strength for each FA variation at 28 days is shown in Table 7. The individual compressive strength of the 100 cm cylinder samples after being converted to a cylindrical shape of 150 cm with a ratio of 0.962 was ranging from 36.72 - 49.61 MPa. Table 8 shows that the compressive strength increases correspondingly increasing the percentage of SCC FA up to 20%. This fact highlights that the ratio of compressive strength to binder is more effective than the research of Siddique [4]. In this study, the ratio of compressive strength to binder ranges from 7.12 to 8.15 while in Siddique's study the ratio ranged from 5.39 to 6.40. Table 8 also shows the highest average compressive strength of 46.79 MPa was recorded at the SCC20, slightly lower than the compressive strength target. Based on the compressive strength achieved, SCC15 and SCC20 can be categorized as high strength concrete. The results of this study show that the use of local Aceh FA originating from the Nagan Raya provides a satisfactory characteristic, both in the fresh and hardened state.

4. **Conclusions**

According to test results, it concluded that allowing local Aceh fly ash originating from Nagan Raya to use for producing self-compacting concrete with up to 20% of cement weight and it provides the results of fresh concrete characteristics appropriate to ACI 237R-07 and EFNARC standard requirements. Furthermore, the use of Nagan Raya fly ash positively influences the compressive strength which SCC compressive strength increases by increasing FA percentages in the mixture up to 20% of the cement weight. The compressive strength of SCC containing Nagan Raya fly ash reached up to the 46 MPa which it can categories as high strength concrete.

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