Study on Compressive Strength of Self-Compacting Concrete (SCC) Based on Fly Ash

Guoping Yu¹, Ru Chen², Changtai Luo² and Banghua Xie²*

¹ China Nerin Engineering Co., Ltd., Nanchang 330038, China
² School of Civil Engineering and Architectural, Nanchang institute of Technology, Nanchang, Jiangxi, 330099 China
Email: ryn2001@163.com

Abstract. Fly ash (FA) has a good effect on the fluidity and strength of self-compacting concrete (SCC). The experimental research method was adopted, equipped with C35 self-compacting concrete, $w/c = 0.4$ and FA content $\alpha = 0\% - 40\%$. The compressive strength of SCC was studied for $T = 3d, 7d, 14d, 28d, 60d$. It is found that FA has a great impact on the compressive strength of SCC. With the continuous addition of FA, the strength of SCC increases at first, and then decreases. When $\alpha = 25\%$, the compressive strength of SCC is best, reaching 47.3 MPa. As with ordinary concrete, the strength of SCC varies with curing time. When $T = 7d-14d$, SCC strength increases less.

Keywords. Strength test, FA, SCC, compressive strength.

1. Introduction
Self-compacting concrete (SCC) has better self-compacting property and fluidity, the workability of SCC can be improved by adding fly ash, and the hydration heat can be reduced. Fly ash directly affects the mechanical properties and economic indexes of SCC. In prefabricated buildings, the application of fly ash in SCC is particularly important.

Hongwei Han [1] et al studied SCC with low water-binder ratio, and fly ash can effectively reduce the crack caused by plastic shrinkage of concrete to improve its strength. Lingzhu Zhou [2] et al studied the effect of fly ash on SCC, and found that with the fly ash content increased, the compressive strength of concrete in the early stage increases slowly. With the increase of curing time, the chemical reaction of FA is slow, which improves the strength of concrete in the later stage. The hydration heat generated by the hardening of cement gelled materials will increase the temperature difference between inside and outside concrete. The hydration heat of concrete can be reduced effectively by adding FA. At 14d age, the hydration heat of concrete is about 30% less than that of pure cement concrete and about 10% less than that of 28d [3]. In order to studying the effect of FA, Weirong Huang [4] et al studying SCC C30, FA can improve the fluidity, and it can improve the strength. For ordinary concrete, adding fly ash will reduce the strength. Shengyu Cai [5] et al adding FA $\alpha = 30\% - 60\%$, found that due to the micro aggregate effect of FA, with adding more FA, the total area of cracking effectively decreased. Tinglin Jiao [6] et al found that when fly ash of 20 kg, 40 kg and 60 kg (33%) was added to SCC, while the longer the curing time, the compressive strength still gradually increased. Shiquan Li [7] et al explained the main reason why the compressive strength decreases with adding more fly ash, that is, the incorporation of FA will weaken the relationship between MKP crystals. By adding 10%~50% fly ash, Xingxiang Shi et al found that adding fly ash less than 40%, the fluidity of concrete increases with adding FA. When adding FA exceeds 40%, it
will increase the cohesion of concrete [8]. Guorong Li [9] et al showed that adding FA above 25\%, the concrete will increase its strength, and the addition of FA will change the frost resistance. In practical engineering application, the incorporation of fly ash should be reasonably controlled. Jian Cao [10, 11] et al studied the compressive strength of concrete, and adding high FA, and changes the curing age, and the strength growth tends to be flat, so does the change of elastic modulus. When $\alpha = 0\%$, 15\%, 30\% FA is added, the creep of concrete decreases with the adding of FA.

There are still many studies on improving concrete strength with fly ash, but there are few reports on self-compacted concrete, especially when fly ash content is high. In this paper, on the basis of controlling the strength of SCC C35, the compressive strength of SCC C35 is studied, when FA $\alpha = 0\%$~40\%, so as to obtain the FA content with the optimal compressive strength index of SCC C35.

### 2. Methods and Materials

#### 2.1. Experimental Materials

The cement adopts Jiangxi Conch P.O.32.5 ordinary Portland cement; the powder ash adopts Jiangxi Fly ash II. Grade powder ash; the aggregate is local crushed stone in Nanchang, Jiangxi Province, and the fine stone diameter is between 4.75 mm~9.5 mm, which is qualified for grading. The sand is the Nanchang’s river sand in Jiangxi Province, and the fine module is 2.1 after testing. The water reducing admixture is polycarboxylates high performance water reducing admixture, and add 26\%. The test water is tap water.

#### 2.2. Test Method

The mix ratio of C35 self-compacting concrete is configured in accordance with the “Code for Design of Mix Ratio of Ordinary Concrete” (JGJ55-2011). The water-cement ratio is 0.40, and the dosage of poly-carboxylic acid water reducer is 1\%, as shown in Table 1. The strength of SCC was determined by using 100 mm $\times$ 100 mm $\times$ 100 mm cube test blocks, and 9 groups of samples were prepared in total. According to relevant specifications, the strength grade of concrete should be based on the strength of a cube specimen with a side length of 150 mm. Therefore, in the calculation of strength, the measured compressive strength of SCC should be multiplied by a coefficient of 0.95. According to the “Standard of Test Methods for Mechanical Properties of Ordinary concrete” (GB/T50081-2002), a universal testing machine was used to conduct compressive tests on concrete, and the compressive strength of SCC at T=3d, 7d, 14d, 28d and 60d were determined respectively, and the test data were analyzed.

| The compressive number | Water cement ratio | Water | Cementing material | Sand | Finger stone |
|------------------------|-------------------|-------|--------------------|------|-------------|
| S-1                    | 0.40              | 175   | 500                | 0%   | 602         | 1118       |
| S-2                    | 0.40              | 175   | 475                | 5%   | 25          | 602        | 1118       |
| S-3                    | 0.40              | 175   | 450                | 10%  | 50          | 602        | 1118       |
| S-4                    | 0.40              | 175   | 425                | 15%  | 75          | 602        | 1118       |
| S-5                    | 0.40              | 175   | 400                | 20%  | 100         | 602        | 1118       |
| S-6                    | 0.40              | 175   | 375                | 25%  | 125         | 602        | 1118       |
| S-7                    | 0.40              | 175   | 350                | 30%  | 150         | 602        | 1118       |
| S-8                    | 0.40              | 175   | 325                | 35%  | 175         | 602        | 1118       |
| S-9                    | 0.40              | 175   | 300                | 40%  | 200         | 602        | 1118       |

### 3. Results and Discussion

Fly ash has the characteristics of spherical particles, smooth surface, and is widely used in ordinary concrete. The fluidity of SCC can be improved by fly ash. The experiment shows that the fly ash content increased, the fluidity of SCC increased. The compressive strength of ordinary C35 concrete is
35 MPa in 28d and 11.5 MPa, 20.4 MPa and 27.7 MPa respectively in the curing period of 3d, 7d and 14d. The compressive strength of SCC C35 with FA on 3d, 7d and 14d reaches the maximum value of 28.7MPa, 34.9 MPa and 35 MPa respectively, which are 149.5%, 71.1% and 26.4% higher than that of ordinary concrete. The compressive strength of SCC C35 is calculated according to the 150 mm × 150 mm × 150 mm marked test block, as shown in table 2.

Table 2. Compressive strength of SCC(MPa)

| The compressive number | $f_{c}$-compressive strength (MPa) |
|------------------------|----------------------------------|
|                        | 3d | 7d | 14d | 28d | 60d |
| S-1                    | 27.1 | 34.4 | 33.5 | 35.6 | 35.7 |
| S-2                    | 30.2 | 34.1 | 33.5 | 34.4 | 41.3 |
| S-3                    | 28.7 | 34.5 | 33.7 | 36.5 | 44.1 |
| S-4                    | 26.0 | 34.9 | 34.5 | 39.2 | 45.7 |
| S-5                    | 24.1 | 34.7 | 35.0 | 40.8 | 46.8 |
| S-6                    | 23.6 | 33.6 | 34.2 | 40.5 | 47.3 |
| S-7                    | 23.6 | 31.2 | 32.4 | 38.2 | 46.8 |
| S-8                    | 22.2 | 27.5 | 29.6 | 34.5 | 43.6 |
| S-9                    | 15.7 | 22.3 | 24.9 | 31.1 | 35.5 |

3.1. Effect of FA on Compressive Strength of SCC
As is known to all, the porosity of concrete directly affects the strength of concrete. Adding FA into SCC can reduce the porosity of self-compacting concrete and make the cement matrix more compacted. As shown in figure 1, FA has an obvious influence on the strength of self-compacting concrete at all ages. With adding FA increased, the strength of SCC first increases and then decreases. When 20% FA is added, SCC strength in 7d reaches 34.7 MPa and 99.1% of the strength of C35 concrete in 28d, 60d strength up to 46.8 MPa.

Figure 1 (a) shows that during curing 3d, with adding more FA, the strength of SCC decreases, mainly because the number of hydration products of SCC 3d decreases with the continuous adding FA replacing cement, and the secondary hydration is not obvious. When the curing age of SCC is 7d and 14d, adding FA less than 20%, the strength of self-compacting concrete has little influence. When adding FA greater than 20%, the concrete strength decreases with adding FA. When SCC curing age $T=28d$, the SCC strength mixed with 20% fly ash is the highest. Compared with ordinary concrete, its strength increases by 14.8%, and when the fly ash content $\alpha=10\%-30\%$, the compressive strength of SCC increases by 2.5%, 10.1%, 13.8% and 7.3%, respectively, reaching 35 MPa. When fly ash is added to 35% and 40%, the concrete strength decreases by 3.1% and 12.6%, mainly because the fly ash is added to reduce a large amount of cement, reduce the cementing material greatly, and fly ash activity is low, and hydration reaction is slow. As shown in figure 1 (d), when FA $\alpha=20\%-25\%$, SCC-C35 strength at $T=28d$ is relatively large, and the fly ash content is optimal. With the FA again hydration reaction fully occurred, SCC strength at 60d with $\alpha=5\%-35\%$ increased by 15.7%, 23.5%, 28%, 31.1%, 32.5%, 31.1% and 22.1%, respectively, compared with ordinary concrete. When FA $\alpha=40\%$, the compressive strength of self-compacting concrete reaches 35.5 MPa, and its compressive strength is basically the same as that of the test block ordinary concrete. Considering the strength and economic index of SCC, 40% of the fly ash of SCC-C35 can be selected.
3.2. Effect of Curing Age on Compressive Strength of SCC

As shown in Figure 2, the SCC strength curing increases the most between 3d and 7d, while the strength increases less between 28d and 60d. With increase curing time, the microaggregate effect of FA and the reaction of FA with cement and water will increase the compressive strength of the concrete test block. When the fly ash content is 25%, the 60d strength reaches the best. With increase curing time, the SCC strength at 14d to 60d growth is obvious, because hydroxyl ions in concrete with cement hydration increase gradually, fully reaction of fly ash, fly ash particles within the concrete to fill at the same time, and in the chemical and physical properties on reinforced concrete in the late strength.

It is well known that the concrete strength is affected by certain curing age, and the relationship between the ordinary concrete strength and curing age is following as [12]:

$$f_{cc, T} = f_{cc, 28} \times \frac{\log T}{\log 28}$$

where, $T$ is the curing age; $f_{cc, T}$ is the compressive strength of ordinary concrete cured in $T$ days; $f_{cc, 28}$ is the compressive strength of concrete cured for 28d. As shown in Figure 2, with the increase of curing period, the strength of SCC C35 with fly ash shows an overall trend of increase, and the growth is obvious. The relationship between the strength of self-compacting concrete and curing period conforms to equation (1).
4. Conclusion

When the water-cement ratio is 0.4, fly ash can better improve the compressive strength of self-compacted concrete, the compressive strength of each age changes significantly, and can effectively reduce the economic index of self-compacted concrete. The research on compressive strength of SCC C35 mainly comes to the following conclusions:

(1) With 20% fly ash, the strength of C45 self-compacted concrete reaches 34.7MPa in 7d and 46.8MPa in 60d. When the incorporation amount was 25%, the compressive strength reached the highest at 60d (47.3MPa).

(2) Fly ash $\alpha=25\%$ is the best effect of replacing cement; In combination with the mechanical and economic indexes of self-compacting concrete, the economic content of fly ash is 40%.

(3) When fly ash is added, the relationship between strength and curing age of SCC conforms to the relationship curve of ordinary concrete.

**Figure 2.** The relationship between the compressive strength of SCC and curing age.
Acknowledgments
This research work was Financially supported by the science and technology research project in Jiangxi province department of education (NO.GJJ161120, GJJ180956, GJJ190948, GJJ200947, GJJ200966 ) and the key project of advantageous science and technology innovation team of Jiangxi province (NO.20171BCB19001).2018 National “Innovation and Entrepreneurship” Training Program for College Students.

References
[1] Han H W 2020 Effect of fly ash on volume stability of low-water-binder ratio concrete Cryogenic Building Technology 42(08) 32-34+52.
[2] Zhou L Z, Zheng Y, Luo Y B, Zhan F Y and Sun C 2017 Research on performance of self-compacting concrete with high fly ash content Concrete (11) 63-67+73.
[3] Pu Z H, Yao R S, Sun M G, Ji W S and Gao Y B 2020 Study on the influence of fly ash content on adiabatic temperature rise of concrete Low Temperature Building Technology 42(07) 50-52.
[4] Huang W H and Guo G X 2015 Effect of fly ash content on C30 self-compacted concrete Concrete (04) 119-122.
[5] Cai S Y, Shen H H and Gao L 2020 Research on the Influence of fly ash content on anti-cracking performance of self-compacting concrete at early age Concrete World (04) 77-81.
[6] Jiao T L, Liu S J and Gao X Y 2019 Research on fly ash in Concrete Concrete World (10) 76-79.
[7] Li S Q, Yu X F, Cao L J, Yin J M, Wu W S and Tao Y T 2019 Experimental study on fly ash modified Magnesium phosphate Cement Concrete (4) 111-113.
[8] Shi X X, Liu Y X, Pu Q, Tian Y and Chen J J 2017 Effect of highly efficient water-reducing agent and fly ash on the performance of self-compacting concrete Concrete and Cement Products (12) 14-18.
[9] Li G R and Liu Y Z 2019 Research on frost resistance critical strength of concrete with large amount of fly ash Comprehensive Utilization of Fly Ash (2) 61-64.
[10] Cao J, Liu L F, Zhang W P, Gong Y F and Zhang C 2017 Research on the development of mechanical properties of concrete with high content of fly ash with age Journal of Nanchang Institute of Technology 36(6) 62-66.
[11] Cao J, Wang Y F, An X P and Gong J G 2015 Research on the creep coefficient of axial compression fly ash concrete members Journal of China Highway 28(3) 73-81.
[12] Wang G X, Wang Y R and Yang K 2014 Experimental study on compressive age strength of carbon fiber grey ceramsite concrete Engineering Construction 46(05) 4-7.