Research on the mechanical properties of composite admixture concrete

Yongwen Li, Yongping Zhang and Zaibo Li*

School of Chemistry and Civil Engineering, Shaoguan University, Shaoguan, Guangdong, 512005, China
*Corresponding author’s e-mail: lizaibo@sgu.edu.cn

Abstract. The effect of high-efficiency composite activator on the working performance and mechanical properties of composite admixture concrete composed of steel slag (SS), blast-furnace slag (BS) and fly ash (FA) were studied in this paper. Results show that: the use of composite activator has no adverse effect on the working performance of fresh concrete; the effect of composite activator on the improvement of the compressive strength of C30 is obvious, while the effect on C50 concrete is weakened. The reason is that when the cement content per unit volume of concrete is high, cement has a certain inhibitory effect on the hydration of steel slag in the early stage.

1. Introduction
Steel slag (SS) is the molten slag discharged during the steelmaking process, which belongs to bulk industrial solid waste. At present, the annual steel output has reached 995 million tons in china, and accordingly, the total annual steel slag emission exceeds 100 million tons. Abandoned steel slag not only occupies a lot of land, destroys the vegetation structure of the land, but also causes secondary pollution of air and water quality, and seriously damages the ecological environment. Therefore, it is of great practical significance to vigorously carry out the comprehensive application research of steel slag and realize the secondary resource utilization and efficient utilization of steel slag.

The steel slag contains a certain amount of C2S, C3S and other main minerals of clinker, which has the basic conditions for being used as a cement and concrete admixture [1], and steel slag powder can improve the wearability, resistance to carbonization and compensation for shrinkage of concrete [2, 3]. The use of steel slag as an auxiliary cementitious material for cement and concrete may become an important way for efficient recycling of steel slag. On the basis of previous research work [4, 5], a composite admixtures composed of steel slag (SS), blast-furnace slag (BS) and fly ash (FA) (hereinafter referred to as "composite admixtures") was prepared and the influence of composite activator on the physical and mechanical properties of concrete were studied.

2. Raw materials
Blast-furnace slag (BS) and steel slag (SS) are provided by Guangdong Shaoguan Iron and Steel Group Co., Ltd., and the Blaine specific surface area of the powder is controlled at 400 m²·kg⁻¹. The fly ash (FA) adopts the second grade fly ash from Shaoguan Power Plant, with a 0.045mm sieve residue of 12.6%. The cement used in this paper is 42.5 grade ordinary Portland cement. The composite activator is composed of two industrial grade chemical reagents, A and B. The maximum particle size of the sand Dₘₐₓ=5mm, the fineness modulus is 2.51, and the moisture content is 5.7%.
The stones are continuously graded 5-20mm. The admixtures are UNF-5 water reducing agent and UNF-5AS retarder. The chemical composition and powder density of cement, blast furnace slag, steel slag and fly ash are shown in Table 1.

### Table 1: The chemical composition of raw materials (wt.%)

| Raw materials       | CaO  | SiO₂ | Al₂O₃ | MgO  | SO₃ | MnO  | f-CaO | Density (kg·m⁻³) |
|---------------------|------|------|-------|------|-----|------|-------|-----------------|
| Cement              | 63.11| 23.52| 4.48  | 1.28 | 2.87| —    | 0.36  | 3140            |
| Blast furnace slag  | 38.29| 35.07| 14.27 | 8.39 | 2.89| 0.34 | 0.88  | 2910            |
| Steel slag          | 49.11| 18.18| 1.05  | 6.74 | 0.48| 2.79 | 4.34  | 3210            |
| Fly ash             | 6.84 | 49.85| 25.74 | 0.62 | 1.58| —    | —     | 2090            |

#### 3. Methods

According to the mix ratio of C30 and C50 grade concrete in commercial concrete mixing plants, steel slag is used to replace one third of blast furnace slag, and the influence of A and B components in the composite activator on the compressive strength of concrete is studied.

In the concrete preparation test, keeping the total amount of concrete cementing material unchanged, the mass ratio of composite admixture and Portland cement is 1:1. By adjusting the mixing water volume, the slump of C30 grade fresh concrete is controlled to (200±10) mm, and the slump of C50 grade fresh concrete is controlled to (210±10) mm. The size of the concrete molded specimen is 150mm×150mm×150mm. After demoulding, the specimens were cured in the curing room. Strength measurements were carried out after 7, 28, and 90 d of curing. The compressive strength of concrete is test according to the requirements of GB/50080-2019.

#### 4. Results and analysis

##### 4.1. The mixing ratio of concrete

The mixing ratio of the prepared C30 and C50 concrete is shown in Table 2.

### Table 2: The mixing ratio of concrete (kg·m⁻³)

| Concrete | Cement | Sand | Stones | BS | FA | SS | Total cementitious material | Water reducing agent | Retarder |
|----------|--------|------|--------|----|----|----|----------------------------|----------------------|----------|
| C30      | 190    | 826  | 1000   | 84.5| 63.3| 42.2| 380                        | 3.04                 | 3.04     |
| C50      | 240    | 704  | 1060   | 106.7| 80.0| 53.3| 480                        | 3.84                 | 3.84     |

##### 4.2. Results

The concrete sample number, water consumption, slump of fresh concrete, and 3d, 7d and 28d compressive strength results of hardened concrete are shown in Table 3.

##### 4.3. Analysis

##### 4.3.1 The influence of steel slag and compound activator on the performance of concrete

During the concrete preparation, it was found that: compared with the freshly mixed BS-FA concrete (reference sample numbered a), the SS-BS-FA freshly mixed concrete has a good performance regardless of whether a compound activator is added or not. There is no obvious bleeding ring around the pile, and the collapsed pile shape is good. The aggregate has been completely wrapped by the slurry, showing high cohesion.
It can be seen from Table 3 that under the control of the slump of the fresh concrete within the range of ±10 mm, the water consumption of concrete prepared after replacing one third of the BS with SS can be reduced by more than 2%. The amount of water used in the preparation process is related to the amount and matching of the A and B components in the composite activator. It can be seen that admixtures prepared with suitable compound activator content can improve the performance of concrete to a certain extent.

Table 3 The effect of compound activator on the mechanical properties of concrete

| Samples | Activator A | Activator B | Water consumption (kg·m⁻³) | Slump (mm) | Compressive strength (MPa) |
|---------|-------------|-------------|----------------------------|------------|---------------------------|
| C30-a   | 0           | 0           | 160.1                      | 205        | 22.3 36.4 45.1            |
| C30-b   | 0           | 0           | 154.1                      | 200        | 19.8 35.8 50.3            |
| C30-1   | 0.30        | 0.40        | 157.7                      | 190        | 23.8 35.4 48.2            |
| C30-2   | 0.30        | 0.60        | 154.5                      | 190        | 25.0 38.2 48.4            |
| C30-3   | 0.30        | 0.80        | 151.6                      | 190        | 26.5 42.7 52.3            |
| C30-4   | 0.45        | 0.40        | 154.8                      | 200        | 25.2 40.7 50.6            |
| C30-5   | 0.45        | 0.60        | 153.5                      | 190        | 26.7 39.7 50.2            |
| C30-6   | 0.45        | 0.80        | 155.3                      | 200        | 26.3 40.3 50.2            |
| C30-7   | 0.60        | 0.40        | 153.5                      | 195        | 27.6 39.8 52.1            |
| C30-8   | 0.60        | 0.60        | 156.4                      | 200        | 23.5 36.5 47.8            |
| C30-9   | 0.60        | 0.80        | 156.7                      | 205        | 24.6 39.1 49.5            |
| C50-a   | 0           | 0           | 163.7                      | 210        | 35.7 46.1 59.0            |
| C50-b   | 0           | 0           | 160.5                      | 210        | 32.1 47.1 59.1            |
| C50-1   | 0.30        | 0.40        | 155.0                      | 215        | 39.1 51.9 61.2            |
| C50-2   | 0.30        | 0.60        | 160.3                      | 205        | 38.3 49.0 61.1            |
| C50-3   | 0.30        | 0.80        | 162.9                      | 220        | 38.4 48.1 60.7            |
| C50-4   | 0.45        | 0.40        | 160.0                      | 210        | 37.1 50.2 62.0            |
| C50-5   | 0.45        | 0.60        | 156.9                      | 210        | 38.4 48.2 58.4            |
| C50-6   | 0.45        | 0.80        | 157.1                      | 220        | 39.4 50.1 62.9            |
| C50-7   | 0.60        | 0.40        | 161.3                      | 220        | 35.2 46.9 58.8            |
| C50-8   | 0.60        | 0.60        | 158.4                      | 200        | 37.9 50.9 60.6            |
| C50-9   | 0.60        | 0.80        | 162.9                      | 205        | 38.1 49.5 61.5            |

Note: C30 and C50 represent the design grade of concrete. Number a is a comparative sample, which means that no steel slag and composite activator are added, and the ratio is BS:FA = 2:1. Number b is a comparative sample, which means that steel slag is added but no composite activator is added, and the ratio is BS:FA:SS = 2:1.5:1. The samples numbered 1-9 have the same ratio as b, but mixed with different proportions of composite activators.

4.3.2 The effect of compound activator on the mechanical properties of concrete

It can also be seen from Table 3 that the 3d compressive strength of C30 concrete prepared by replacing one third of BS with SS is reduced by 11.2%, and C50 concrete is reduced by 10.1%. After curing for 7d and 28d, the compressive strength of sample b approaches or even exceeds that of
sample a. It can be seen that the compound mixing of SS will cause the 3d compressive strength of concrete to decrease significantly. However, if it is combined with a composite activator during the preparation process, the 3d compressive strength of C30 and C50 concrete can be increased by 18%–39% and 10%–21%, respectively, which reflects the excellent effect of the composite activator in multi-component cementing system. The increase in compressive strength of concrete 7d and 28d decreased to different degrees. The results of this test are related to the amount and matching of the A and B components in the composite activator.

5. Discussion
From the current technical level, adding an activator is a necessary technical means to obtain high-performance cementitious materials. In this study, the compound activator incorporated has two functions. One is to promote the hydration of the effective active components in the steel slag and to accelerate the disintegration of the glass phase of blast-furnace slag and fly ash; the other is to build a better environment to generate hydration product through the adjustment and optimization of the concentration of various ions. The steel slag-based cementitious material is in a multi-ion coexistence system when it is hydrated. The coexistence system has a certain influence on the type, quantity and speed of the hydration products, and then affects the effect of the composite activator. Steel slag is similar to low-quality Portland cement clinker. After contact with water, steel slag will hydrate and release calcium hydroxide. The test results show that, compared with the C30 concrete, the cement content in the unit volume of C50 concrete is larger, and the rapid dissolution and mass dissolution of CaO in the cement have a certain inhibitory effect on the hydration of steel slag in the cementitious material in the early stage, thus restricting the effect of the composite activator, and obviously weakening the effect of the composite activator on the compressive strength of C50 concrete.

6. Conclusions
For the concrete prepared with SS-BS-FA composite admixture and the same amount of Portland cement, the use of composite activator has no adverse effect on the performance of fresh concrete. The compound activator has obvious effect on C30 concrete, but its effect on C50 concrete is weakened. The reason is that when the cement content per unit volume of concrete is high, cement has a certain inhibitory effect on the hydration of steel slag in the early stage.

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References
[1] Samir I. Abu-Eishah, Amr S. El-Dieb, Mostafa S. Bedir (2012) Performance of concrete mixtures made with electricarc furnace (EAF) steel slag aggregate produced in the Arabian Gulf region, Constr. Build. Mater. 34: 249–256.
[2] M.C.G. Juenger, R. Siddique (2015) Recent advances in understanding the role of supplementary cementitious materials in concrete, Cem. Concr. Res. 78: 71–80.
[3] T. Luo, Q. Wang, S.Y. Zhuang (2019) Effects of ultra-fine ground granulated blast-furnace slag on initial setting time, fluidity and rheological properties of cement pastes, Powder Technol. 345: 54–63.
[4] Z. Li, X. Zhao, T. He, S. Zhao (2017) A study of high-performance slag-based composite admixtures, Constr. Build. Mater. 155: 126–136.
[5] F. Messina, C. Ferone, F. Colangelo (2015) Low temperature alkaline activation of weathered fly ash: Influence of mineral admixtures on early age performance, Constr. Build. Mater. 86: 169-177.