Experiment Research on the Mechanical Performance of Alkali-activated Slag Cementitious Material

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Abstract. The influence of three different kinds of alkali (sodium hydroxide, sodium sulfate and water glass) excitation agents on the mechanical properties of slag cement materials has been studied by compressive test. The results show that the effect of excitation of sodium silicate is better than that of sodium hydroxide and sodium sulfate, with the increase of alkali equivalent excitation agent, compressive strength of mortar specimens remarkably, compared with alkali equivalent of 3.1% of the sodium sulfate, the 28d compressive strength of mortar specimens with alkali equivalent of 4.65% and 6.2%, has been increased by 140% and 31.5% respectively.

1. Introduction

Alkali activated materials (AAMs) are green materials which produced by activating a high calcium alumina silicate precursor with an alkali source, and can be used in place of Ordinary Portland Cement[1-7]. The industrial by-products such as metal production alumina silicate sources often used in AAMs [8-10]. Being high embodied energy and generated carbon, the application of AAMs is more sustainable than Ordinary Portland Cement [9]. Besides, alumina silicate is always considered as waste product, applying it for concrete production not only reduce its negative impact on the environment, but also lower cost of landfilling the material [10]. Studies in [6] indicate that nearly 75% of CO₂ emission can be reduced by using AAMs. The review in [7] shows alumina silicate precursors are most generated by slag and fly ash and it has been estimated that annual global production of slag is about 320 Mt [8].

With rapid development of China's iron and steel industry, the increasing utilization of coal resources and slag production in China rise to nearly 2, 400 million tons, by 2020 the emissions of fly ash in China is expected to reach 900 million tons, the production of slag and fly ash has become a huge industry by-products. Industrial by-product (slag, fly ash, etc.), natural mineral (kaolin, etc.) as the raw material of alkali excitation gelled material, with green, no pollution, low cost and huge potential market, conform to the inevitable for the construction of environmental friendly society in China, especially in the 21st century the most promising inorganic nonmetallic cementing materials. So, AAMs has a broad application prospect in China.

However, alkali slag excitation mechanism of the complex, factors affecting alkali excitation slag cementing material strength more [9], such as slag and material properties of excitation agent, the fineness of slag, kinds and concentrations of alkaline exciting agent and curing condition and age, etc.
In this paper, the types of exciting agent and alkali equivalent for variables, exciting agent were analyzed its influence on the development of the mechanical strength of alkali slag cementing material, the conclusion can stimulate the slag concrete as a base to promote the provides the basis.

2. Experimental research

2.1. Raw materials
Alkali activated Slag was applied as substrate in this experiment, which was supplied by Haode Company in China and the chemical composition is indicated in Table 1. Three different kinds of activators (NaOH, Na₂SO₃ and Water Glass) with different concentration of 3.1%, 4.65% and 6.2% have been used in this study. Among them, the sodium hydroxide and sodium sulfate is analytical pure grade, and concentrate modulus of water glass is 3.2, the slag was stimulated by sodium hydroxide (technical grade) solutions.

Silica sand with fineness modulus of 2.7 and density of 2.5g/cm³ was used as aggregate to prepare the mortars. According to the chemical composition of slag, can calculate the following quality index:

Hydraulicity index:
\[ b = \frac{CaO + MgO + Al_2O_3}{SiO_2} = \frac{42.61 + 8.71 + 15.08}{29.13} = 2.28 > 1 \]

Activity coefficient:
\[ H_0 = \frac{Al_2O_3}{SiO_2} = \frac{15.08}{29.13} = 0.52 > 0.25 \]

Alkaline coefficient:
\[ M_0 = \frac{CaO + MgO}{SiO_2 + Al_2O_3} = \frac{42.61 + 8.71}{29.13 + 15.08} = 1.16 > 1 \]

The quality factor:
\[ K = \frac{CaO + MgO + Al_2O_3}{SiO_2 + MnO + TiO_2} = \frac{42.61 + 8.71 + 15.08}{29.13 + 0.344 + 0.94} = 2.18 > 2 \]

By the quality index, the test using slag is highly active, alkaline slag with high quality, satisfies the requirement of national standard for slag cement for production.

Table 1. Chemical composition of slag

| Composition | CaO  | SiO₂ | SO₃ | MgO  | Al₂O₃ | MnO  | TiO₂  | Fe₂O₃ |
|-------------|------|------|-----|------|-------|------|-------|-------|
| wt%         | 42.61| 29.13| 1.80| 8.71 | 15.08 | 0.344| 0.94  | 0.458 |

2.2. Sample preparation
Mortar specimens were prepared using an aggregate/slag ratio of 3/1 and water binder ratio of 0.5. In this study, each mortar specimen was prepared by the composition shown in Table 2. Samples were mixed according to the standard GB/T17671-1999.

2.3. Experimental procedure
To perform this test, prism specimens with dimension of 40mm×40mm×160mm were used. The samples were cured in standard condition (90% relative humidity (RH), 20 ± 2°C) for 3d, 7d and 28d. Then, the mechanical test was carried out on the basis of GB/T17671-1999.
Table 2. Composition of mortar

| Group     | Concentration (Na₂O%) | sand (g) | slag (g) | activator (g) |
|-----------|------------------------|----------|----------|---------------|
| NaOH      | 3.1                    | 1350     | 450      | 225           |
|           | 4.65                   | 1350     | 450      | 225           |
|           | 6.2                    | 1350     | 450      | 225           |
| Na₂SO₃    | 3.1                    | 1350     | 450      | 225           |
|           | 4.65                   | 1350     | 450      | 225           |
|           | 6.2                    | 1350     | 450      | 225           |
| Water glass | 3.1                  | 1350     | 450      | 225           |
|           | 4.65                   | 1350     | 450      | 225           |
|           | 6.2                    | 1350     | 450      | 225           |

3. Test results and discussion

It can be seen from Table 2 that slag has not been used as gelled material but OPC, and the activator agent will seriously affect the developing of mechanical behavior. From the viewpoint of activator type and alkali equivalent, this paper discusses the exciting agent on the mechanical behavior of slag cement specimen.

3.1. The influence of alkali activator

Determination of 3d and 28d curing ages, alkali excitation compressive strength of mortar specimens, Fig. 1 compares the different excitation agent on the compressive strength of sand.

![Figure 1. The effect of activator type on the compressive strength](image)

(a) 3d
(b) 28d

According to early compressive strength at 3d shown in Fig. 1 (a), for the concentration of 3.1%, the compressive of group of sodium hydroxide is higher than the other two. With the increasing of concentration from 3.1% to 6.2%, the influence of WG is outstanding. For the specimen activated by sodium sulfate, the early strength is worse unable measure. The influence of three different catalysts on the 28d compressive strength is compared in Fig. 1 (b). The strength of group WG with concentration of 6.2% is 78MPa, which is 3.3 times that of group sodium hydroxide and 3.1 times of group sodium sulfate, respectively. The stimulating effect of sodium sulfate is second obvious than that of sodium hydroxide, which is consistent of the result in [10] and [11].

With the developing of curing age, the compressive strength has been greatly inspired in 20MPa~30MPa by WG, that of the other two group ranges from 7MPa to 10MPa.
3.2. The influence of Alkali equivalent
Besides the impact of activated agent, the effect of concentration of activator on compressive strength of mortar has been compared in Fig. 2.

![Graph showing the effect of activator concentration on compressive strength](image)

Figure 2. The effect of activator concentration on the compressive strength

The compressive strength of mortar specimens are activated by alkali activator, which is more obvious with the concentration increasing. The reason may be explained as that alkali solution can accelerate the hydration of slag, the structure of hydration products is more compact and porosity is reduced [9].

In Fig.2 (a), the effect of three different kinds of activator with different concentration on the 3d compressive strength has been compared. It can be concluded that the WG play an important role in improving the early strength than sodium hydraulic and sodium silicate. Owing to the poor early hydration of specimen with sodium sulfate, few hydration products cannot combine sand and even fail in measuring the compressive strength.

In Fig.2 (b) of 28d compressive strength, compared with different concentration of 3.1%, 4.65% and 6.2%, the growth rate of strength of group WG is 140% and 31.5%, respectively. The group sodium hydroxide is increased by 13.4% and 15.8% and that for group sodium sulfate is 18% and 5.5%.

4. Organization of the Text Conclusion
In order to study the effect of different alkali activator with different concentration on mechanical performance of mortar, three kinds of sodium hydraulic, sodium sulfate and WG with concentration of 3.1%, 4.65% and 6.2% was used as activator, and compressive strength test was carried out. Then, the conclusions can be drawn as following:

1. Under the condition of certain alkali equivalent, the influence of WG in three kinds of alkali activator is most obvious, sodium hydroxide follows, and sodium sulfate is worse. Among them, the sodium sulfate stimulate slag mortar cannot hardening at early age. With the concentration increase from 4.65% to 6.2%, the 3d compressive strength of group WG reaches 56.2MPa, far more than that of the other two groups.

2. With the increasing of activator concentration, compressive strength is increased for three kinds of alkali excitation slag mortar, in which group with WG is the most significant. In terms of 28d, compared with 3.1% alkali equivalent, the compressive strength of groups with WG is increased by 140% and 31.5%, respectively. The group sodium hydroxide is increased by 13.4% and 15.8% and that for group sodium sulfate is 18% and 5.5%. Thus, the sequence of influence of alkali activator is WG> sodium hydroxide >sodium sulfate.

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