Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2022, 9(8):11-15

Review Article

ISSN: 2394-2630
CODEN(USA): JSERBR

A review of research progress and development prospects of alkali-activated cementitious materials

Chengxu Yang, Peiqing Li, Xiang Yan

School of Transportation and Vehicle Engineering, Shandong University of Technology, Shandong 255049, China

Abstract Alkali-activated gelling material is a kind of precursor that can activate the activity of precursors in an alkaline or strong alkaline environment. A hydraulic cementitious material that enables it to maintain and develop its properties, and is currently the most widely used alkali-excited material in China. The raw materials are mainly granulated blast furnace slag (GGBFS) and fly ash (FA), and in order to obtain an alkaline environment for the precursor, A stimulator needs to be added. Alkali-excited materials do not need to be calcined in the preparation process, which makes the Compared with traditional cement materials, it can save more resources, and the alkali-activated cementitious materials have a fast setting, Early strength, high-temperature resistance, and other characteristics, these characteristics make it better used in some special occasions, such as rapid setting, The characteristics of early strength can be well applied to engineering repairs, etc., but these characteristics also limit its use in a wider range. Therefore, the main research direction in the world is how to make alkali-excited materials have more. This paper mainly focuses on the research status of alkali-induced cementitious materials in improving rapid setting and early strength. A brief overview of the reaction mechanism of alkali-excited materials is given.

Keywords Alkali excitation, Precursor, Activator, Coagulation time

1. Overview of alkali-excited materials

1.1 Background of the development of alkali-excited materials

As the most commonly used building material in the construction field, cement will cause a large amount of energy during the production and calcination process. It is reported that the carbon dioxide produced by the production of Portland cement (OPC) accounts for 7%~9% of the carbon dioxide produced by all human production activities, and accounts for the world's total energy consumption. 3% of the energy consumption, and with the gradual increase in the fineness of cement in recent years, the resulting energy and economic consumption have also gradually increased. In this case, it is very important to find a cementitious material that can replace cement for civil engineering construction.

1.2 Development history of alkali-excited materials

Alkali excitation materials are mainly composed of industrial wastes such as slag, fly ash, metakaolin, etc. These industrial solid wastes are ground individually or in combination to replace part or all of the cement clinker, and then sodium hydroxide, solid sodium silicate, or water glass are added as activators.

Alkali excitation material, that is, mixing sodium hydroxide solution or other alkaline solution (such as potassium hydroxide, etc.) with solid powder, this mixing method is always in a strongly alkaline environment because of its operation process, not only may the phenomenon of rapid setting occurs, and it may cause personal injury to the operator during production and transportation. Therefore, It was gradually abandoned, and then the research direction gradually shifted to single-component alkali-excited materials, that is, the combination of solid activators with the precursor is fully mixed, and only water needs to be added during the mixing process. This treatment method can improve some of the shortcomings of the two-component to a certain extent.

2. Composition of the alkali-excited material system

2.1 Precursors

The precursors in the alkali-excited materials are mainly responsible for providing elements such as silicon, aluminum, and calcium.

The hydration reaction of these elements during the coagulation process produces ettringite and other substances. The content of these substances is often a key factor in determining the mechanical properties of alkali-excited materials after curing for 7d and 28d. John. L. Provis in the types of precursors are summarized in "Alkali-activated materials" [1]. The available precursors include, but are not limited to, blast furnace slag, fly ash, calcined clay, red mud, steel and copper slag, etc. It can be seen that in the selection of precursors, alkali-excited materials rich in silicon, aluminum, and calcium can be selected. Industrial waste, but for some precursors, the activator that can effectively stimulate its performance has not been found effective. Exciters with excellent performance such as copper slag and municipal solid waste incineration ash.

2.2 Activator

In earlier studies, due to the fact that alkali-excited materials often require high doses of commercial alkali activators and high-temperature environments to achieve curing during the reaction, it has been controversial. Therefore, some researchers [2] partially replaced by using alternative materials. In order to reduce the number of alkaline activators, research was carried out, hoping to improve cost-effectiveness and ecological efficiency in this way, and achieved certain results. In addition, due to the need to deal with a large number of corrosive and dangerous alkaline activators during the use and processing of alkali-activated materials, for the safety of practitioners, researchers [3, 4] began to investigate single-component alkali activators. Inspired material research, ie only dry mixes with hydration. Some researchers are also committed to reducing the number of activators used in the alkali excitation system to achieve more energy savings and environmental protection. H.S.Gökçe et al. [5] found that by controlling the compressive strength of fly ash-based alkali-excited material and alkali-excited Class C fly ash-based mixture can be increased by 102% and 86%, respectively. The total alkali solution consumption of the F-class fly ash-based alkali-excited material and the alkali-excited C-class fly ash-based mixture can be reduced from 718kg/m^3 to 188kg/m^3, and from 769kg/m^3 to 262kg/m^3, respectively.

It is not difficult to see from the above research results that through tailor-made production technology, it is possible to improve the performance of alkali-excited materials while reducing the number of activators, making them more sustainable and economical.

3. Research on retarders

As the main precursors of alkali-excited materials, fly ash and slag have been found in a large number of experiments that their set time is too short, especially for high-calcium precursors such as slag, which will cause transient or flash condensation, and it is impossible to control the setting time. Because the calcium ions present in the slag react with the silicate ions in the pore solution to rapidly form a hydrous calcium silicate gel, this process makes the AAS (alkali-activated slag) mortar harden rapidly, and because of the uncontrollable setting time, it has adverse effects in practical applications, so the regulation of setting time has become one of the main research directions. The mechanism of AAS retardation can be considered from the inhibition of raw material dissolution and inhibition of hydration product deposition, but in silicate excitation In the AAS system, it is extremely difficult to inhibit the deposition of its hydration products, because there is a large amount of silicon itself, which will promote the formation of hydrated calcium silicate and hydrated calcium sulfoaluminate. In previous studies, the researchers found that water reducers or retarders used in common OPCS are largely ineffective or even negatively impact alkali-excited material systems. Even so, researchers have discovered a number of admixtures that can be used in alkali-excited material systems:

Sajjad Yousefi Oderji [6] et al. added FA (Fly ash) and GGBS (granulated blast furnace slag) were mixed in the mixture, and their mechanical strength and setting time were tested and measured. It was found that 4% borax can effectively improve its mechanical properties and improve its setting time, and it was observed by SEM test that in the sample with 6% borax content, a dense linear structure can be observed. At the same time, it is worth noting that the setting time is also significantly improved after adding lignin tricalcium sulfate, but in terms of mechanical properties adversely affected. Ubolluk Rattanasak [7] et al. used calcium chloride, calcium sulfate, sodium sulfate, and sucrose as retarders in alkali-excited fly ash, and found that at the same dosage, sodium sulfate and sucrose were better than those of sodium sulfate and sucrose. Calcium chloride and calcium sulfate have better initial setting times, but in terms of final setting time, the final setting time that sucrose can react with is better, reaching 210-230min (see Table 1).

Table 1: Initial setting and final setting time under different admixture dosages

Admixture	Dosage	Initial setting time	Final setting time
Sodium chloride	1	26	60
	2	35	45
Calcium sulfate	1	58	115
	2	56	105
Sodium sulfate	1	82	135
	2	90	130
sucrose	1	60	210
	2	60	230

Chang et al. [8] found that when phosphoric acid was used as a slag-based material excited by water glass, the retardation effect was very sensitive to the concentration of phosphoric acid. When the concentration of phosphoric acid was below 0.78M, the retardation effect hardly changed. When the concentration exceeds 0.84M, the setting time is significantly prolonged, and when the concentration of phosphoric acid is 0.87M, the initial setting time even exceeds 6h, but the high concentration of phosphoric acid also causes adverse effects such as low early compressive strength and increased drying shrinkage. In the subsequent experiments, they added gypsum to the slag-based materials excited by water glass and found that gypsum could effectively solve the problem of excessive drying shrinkage, the two restrained each other during the reaction, which eventually led to a large difference between the experimental results and the expected results.

It is also worth noting that in previous studies, it was found that in the AAS system excited by sodium carbonate, no admixtures that could effectively improve the setting time were found, while in the sodium hydroxide-excited slag system, lignin sulfate and Methallyl ether (HPEG) superplasticizers (with high electron density and shorter side chains) can effectively improve workability, prolong setting time and increase strength. In addition, adding to alkali-excited material systems A small amount of industrial solid waste such as titanium gypsum and phosphogypsum can also effectively improve its setting time.

4. Application of alkali-excited materials

4.1 Geopolymer Stabilized Gravel (GSM)

Geopolymer Stabilized Gravel (GSM) is the commercial name for alkali-excited stabilized gravel, and unlike geopolymer concrete, the use of alkali-excited materials in pavement construction is relatively new, but some recent studies have demonstrated their usefulness. The feasibility of being used as pavement materials, Yiyuan Zhang et al. [9] evaluated the environmental and energy issues of geopolymer-stabilized crushed stone by using the method of life cycle assessment (LCA), and their evaluation showed that geopolymer-stabilized crushed Stone used in road construction can effectively alleviate the problem of global warming, while the composite activator composed of sodium hydroxide and water glass has a less environmental impact and can ensure certain mechanical properties. In addition, in recent years, scholars have continued to explore the road use possibilities of alkali-activated materials, such as the road performance of waste glass-based alkali-activated materials, and the road performance of fly ash-based alkali-activated materials, and the red mud-based alkali-activated materials. The above studies have shown that it is completely feasible to use alkali-excited materials for roadbed construction. It can be seen that the geopolymer-stabilized crushed stone has broad market application prospects and is of great significance for alleviating global warming and the energy crisis.

4.2 Other applications

In addition to the above two, the application of alkali-excited materials has many other applications. For example, when the alkali-excited material is in a colloidal state, metal aluminum powder is used as a foaming agent to produce a foamed gelling material. Kovalchuk et al. [10] Alkali-excited fly ash-based steam pressurized concrete was developed, and in the Soviet period, alkali-excited slag cement was used in oil well cement, and some alkali-excited materials were also used for sequestration of CO_2, etc. It can be seen that the alkali-excited material has very huge market potential.

5. Conclusion

According to relevant literature reports, no superplasticizer has been found to effectively improve the performance of the slag system excited by sodium carbonate or water glass, and there is almost no report on the combined use of superplasticizer and retarder. The reason is speculated that the combined use of superplasticizer and retarder may produce the result of mutual restraint similar to that of gypsum and phosphoric acid when used together. It can be seen that a large amount of alkali-activated materials is still required to be widely used in practical engineering. practical exploration. However, it is certain that under the background of increasingly serious environmental problems in the world, the wide application of alkali-excited materials is undoubted of great significance, especially the combination of alkali excitation and industrial solid waste (titanium gypsum, phosphogypsum, etc.) It is shown that adding a small amount of titanium gypsum to the AAS system excited by sodium silicate can effectively improve the setting time. Another study shows that adding an appropriate amount of industrial solid waste and fly ash in a certain proportion, such as cement clinker, can effectively improve the semi-rigid base. Cracks caused by expansion and contraction can effectively improve its road performance. It can be seen that the combined use of industrial solid waste and alkali excitation materials can not only effectively improve its existing shortcomings, but also greatly reduce the pollution and waste of industrial solid waste accumulation on land resources and water resources, saving time in engineering construction. Material cost, studies have shown that in practical applications, compared with the use of 32.5 Portland slag cement, each kilometer of roadbed can consume 688.8t of solid waste and save 6.53% of material costs. Some studies have found that when red mud is used as a substitute for cement and fly ash in concrete, it is found that red mud can effectively improve the mechanical properties of other materials when used as a substitute at a lower level, even if the amount of red mud replaced is higher. It can still effectively improve the durability of concrete. According to the experimental results, it can replace 40% of fly ash or 20% of cement in mortar. However, it should be noted that the characteristics of red mud vary significantly depending on its source, so its inclusion must be decided on the basis of the applications and features required for effective use.

Reference

[1]. Provis J L. Alkali-activated materials[J]. Cement and Concrete Research, 2018,114:40-48.
[2]. He Jian, Jie Yuxin, Zhang Jianhong, et al. Synthesis and characterization of red mud and rice husk ash-based geopolymer composites[J]. Cement and Concrete Composites, 2013,37:108-118.
[3]. Luukkonen T, Abdollahnejad Z, Yliniemi J, et al. Comparison of alkali and silica sources in one- part alkali-activated blast furnace slag mortar[J]. Journal of cleaner production, 2018,187:171-179.
[4]. Duxson P, Provis J L. Designing precursors for geopolymer cements[J]. Journal of the American ceramic society, 2008,91(12):3864-3869.
[5]. Gökçe H S, Tuyan M, Ramyar K, et al. Development of eco-efficient fly ash–based alkali- activated and geopolymer composites with reduced alkaline activator dosage [J]. Journal of Materials in Civil Engineering, 2020,32(2):4019350.
[6]. Oderji S Y, Chen B, Shakya C, et al. Influence of superplasticizers and retarders on the workability and strength of one-part alkali-activated fly ash/slag binders cured at room temperature[J]. Construction and Building Materials, 2019,229:116891.
[7]. Rattanasak U, Pankhet K, Chindaprasirt P. Effect of chemical admixtures on properties of high-calcium fly ash geopolymer [J]. International Journal of Minerals Metallurgy and Materials, 2011,18(03):364-369.
[8]. Zhang Junjie. A study on the setting characteristics of sodium silicate-activated slag pastes [J]. Cement and Concrete Research, 2003,33(7):1005-1011.
[9]. Zhang Yiyuan, Gong Hongren, Xi Jiang, et al. Environmental impact assessment of pavement road bases with reuse and recycling strategies: A comparative study on geopolymer stabilized macadam and conventional alternatives[J]. Transportation Research Part D: Transport and Environment, 2021,93:102749.
[10]. Krivenko P V, Kovalchuk G Y. Heat-resistant fly ash based geocements, 2002[C].2002.