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# Research progress on the influence of geopolymer grouting material properties

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**Abstract:** Grouting technology is to inject slurry with cementing ability into the cracks and voids of the formation to achieve the purpose of reinforcement and filling. At present, cement-based materials are mainly used for grouting, which has the advantages of mature technology, cheap price, high stone strength and wide application, but there are also defects such as high-water separation rate, poor stability and long setting time. Most importantly, the production of cement materials consumes a lot of energy and emits a lot of CO2, which aggravates the global greenhouse effect and is not in line with the concept of sustainable development. In recent years, geopolymer materials based on volcanic ash and industrial waste residue have attracted extensive attention of scholars because of their green and environmental characteristics, and have been gradually applied in the field of grouting. Geopolymer is a new inorganic cementitious material formed by leaching the active components (Si, Al, and other elements) from industrial wastes such as fly ash, slag, and steel slag using chemical alkali activation technology (AAT) and further recombination. Using geopolymer as grouting material has two advantages :(1) geopolymer has a wide source of raw materials and low cost, which can effectively reduce the cost of grouting engineering; (2) Compared with cement materials, geopolymer materials have the advantages of low energy consumption, green environmental protection and other advantages, which can realize the effective recovery and reuse of industrial waste residue, reduce a large amount of CO2 emissions, and have far-reaching environmental and social benefits. Among them, temperature is an important factor affecting the properties of geopolymer grouting cementitious materials. In this paper, the effects of the selection of aluminosilicate raw materials, the fineness of raw materials, the ratio of liquid to solid, the type and modulus of alkali activator, and the temperature conditions on the properties of geopolymer grouting cementitious materials are comprehensively combed.

**Keywords:** Geopolymer; Grouting material; Temperature; Performance.

## 1. Introduction

Grouting reinforcement is the injection of grout into soil layer or rock by means of penetration, compaction, splitting and so on, cementing the original loose soil or rock mass cracks to form a stone body with certain reinforcement or impermeable properties. The overall strength of soil or rock mass after grouting is directly related to the strength of grout stone body. At present, the grouting technique has been widely applied to tunnel (hole), mine, water conservancy and hydropower engineering, from foundation to the dam body, from the fracture rock to the karst caves, whether local grouting water plugging, large-scale water conservancy, or underground engineering reinforcement, the slope protection, all kinds of cases of grouting reinforcement technique has been carried out more research.

However in recent years, with the development of economy and the progress of technology, rapid development of traffic engineering in the direction of longitudinal, deep, at the same time, the mine mining depth increasing, high ground temperature (hot harm) problem increasingly become tunnel (hole) engineering, mining engineering and other underground engineering geological problems often encountered, high temperature geothermal phenomenon will make the materials exhibit different properties at ambient temperatures, For example, setting time is shortened, strength is reduced, durability is poor, etc.

With the deterioration of the environment, the shortage of energy, at the same time in order to respond to the call of "green energy saving". All walks of life to carry out a "green revolution". Due to the high energy consumption, high pollution and other shortcomings of cement. For the grouting project with increasing demand, cement grouting will be eliminated. Geopolymers gradually came into view. Geopolymer has attracted more and more attention for its advantages of green environmental protection, excellent performance and wide source of raw materials. It is known as "green cement", which is expected to replace cement and other high-energy cementing materials. Since most industrial wastes contain active components such as active SiO2, active Al2O3 and free calcium oxide, hydration will occur under certain alkaline conditions to form cementitious materials. Scholars at home and abroad try to use geopolymer to prepare new grouting materials to replace cement grouting materials and have made some progress. It is found that geopolymer grouting materials are superior to cement grouting materials in mechanical properties, durability and flow performance.

## 2. Possible effects of different temperatures on properties of geopolymer grouting materials

Geopolymer is a kind of hydraulic cementitious material which is made of inorganic polymer as the main product by natural mineral or industrial waste residue containing appropriate aluminosilicate composition and alkaline activator and water. Among them, the most common aluminum silicate raw materials are metakaolin, fly ash, slag, steel slag, red mud, coal gangue, etc.

### 2.1. Silicon aluminate raw material

Aluminosilicate raw material is the reactive base material

of geopolymer grouting material, its activity degree and the content of calcium oxide have an important influence on the working performance of geopolymer grouting material. Adamiec[1]and Lothenbach et al[2] divided the geopolymer into three systems of high calcium, low calcium and no calcium according to the different Ca/Si ratio in aluminosilicate raw materials[3] . At present, geopolymer grouting materials can be divided into one, two or multiple types according to cementitious materials. The combination of various silicon aluminate, the effect also has the difference. Reasonably adjusting the activity and calcium oxide content of aluminosilicate raw materials is an effective way to adjust the properties of geopolymer grouting materials[10] . In order to respond to the call of green energy saving, give full play to the value of geopolymer, make up for the shortage of single raw material, and improve the utilization rate of raw material. Geopolymer grouting materials are gradually transformed from a single silico-aluminate system to a composite system to maximize the use of a single material. In this paper, the ratio and compressive strength results of composite silica-aluminate materials of geopolymer grouting materials in the study are summarized as shown in Table 1.

**Table 1.** Ratio and compressive strength of geopolymer grouting materials combined with silica-aluminate materials

| Ref | Activate type | Proportion (mass ratio) |
|---|---|---|
| [9] | Sodium silicate, NaOH | $SiO_2 : Na_2O=1.39$ |
| [10] | Sodium silicate, NaOH | $SiO_2 : Na_2O=1.2$ |
| [11] | NaOH | NaOH=1 |
| [12] | Sodium silicate, KOH | $SiO_2 : Na_2O=1.53$ |
| [4] | Sodium silicate, NaOH | $SiO_2 : Na_2O=1.5$ |
| [13] | NaOH | NaOH=1 |
| [14] | Sodium silicate, NaOH | $SiO_2 : Na_2O=1.01$ |

## 2.2. Type and modulus of alkaline activator

Chemical alkali excitation treatment is an effective means to improve the activity and utilization of natural mineral or industrial waste residue. The activator of geopolymer is generally alkaline solution, including calcium hydroxide, potassium hydroxide, sodium hydroxide, sodium silicate, potassium silicate, sodium carbonate and so on. It has been shown that the composition of the initiator has a significant effect on the polymerization reaction, the composition of the polymerization product and the properties of the final product. Higher activator modulus results in stronger ion pair formation, providing additional dissolution rates and completing faster interfacial polycondensation processes[7]. However, too high activator modulus will have a bad effect on the final product. This paper summarizes the types and proportions of alkali activators for geopolymer grouting materials in various studies, and the results are shown in Table 2.

As can be seen from Table 2, many scholars prefer to use sodium silicate solution mixed with strong alkali sodium hydroxide as alkaline activator. At present, the commonly used alkali initiator is sodium silicate solution. The modulus of sodium silicate can be adjusted by adding the content of sodium hydroxide or potassium hydroxide to maximize the activity and utilization of raw materials.

**Table 2.** Types and proportions of alkali activators for geopolymer grouting materials

| Ref | Composition (mass ratio) | 7d compressive strength/MPa | 28d compressive strength/MPa |
|---|---|---|---|
| [4] | Metakaolin : Fly ash =1:1 | ---- | 55.0 |
| [5] | Metakaolin : Cement =7:3 | 16.2 | 17.0 |
| [5] | Metakaolin : Cement =8:2 | 9.0 | 13.5 |
| [5] | Metakaolin : Cement =9:1 | 4.5 | 5.2 |
| [6] | Slag : Lime =8:2 | 24.3 | 30.2 |
| [7] | Cement : Slag =4:6 | ---- | 13 |
| [7] | Cement : Slag : Fly ash =3:2:5 | ---- | 11 |

## 2.3. Fineness and liquid-solid ratio of raw materials

In order to improve the activity of mineral components, related scholars have tried to improve their fineness by physical activation. With the increase of the fineness of aluminosilicate raw materials, the surface area increases, thus improving the level of physical and chemical reactions. Accelerate the rate of dissolution, ion transport and formation of aluminosilicate[8]. The experimental data show that with the increase of fineness, the formation of aluminosilicate core and gel phase of slag, fly ash and metakaolin-based polymer is promoted, and the setting and hardening process is accelerated[3]. In the test process, the mechanical properties of geopolymer grouting material can be adjusted by reasonably selecting aluminosilicate raw materials with different fineness, but too high fineness will cause the gel product to shrink greatly, which is unfavorable to the structure.

Geopolymer grouting materials are different from geopolymer concrete materials. Geopolymer concrete material has high strength requirements and low liquidity requirements, but geopolymer grouting material has high liquidity requirements, accompanied by high mechanical strength, water separation rate, setting time and other properties. The liquid-solid ratio of grouting materials is an important factor affecting the strength of cementitious materials. Panjasila et al[15] used fly ash as silico-aluminate material (liquid-solid ratio 0.4, sodium silicate mixed with sodium hydroxide modulus 1) to prepare alkali excited slurry. Li et al[7] used slag and fly ash mixed with cement as raw materials to study the mechanical properties of grout under different liquid-solid ratio conditions. The setting time of slurry increases with the increase of liquid-solid ratio. With the increase of liquid-solid ratio, the compressive strength of slurry decreases. But the diffusion time of slurry gradually tends to a stable value. Therefore, due to the large amount of water consumption, the fluidity of the grouting material will be increased, which may have an adverse impact on the strength. Therefore, it is necessary to rationally adjust the water consumption according to the engineering condition, the nature of the injected body and other factors, so as to ensure that the geopolymer grouting material has a high strength on the premise of fluidity. At the same time can add appropriate admixture (water reducing agent, swelling agent, retarder, etc.) to improve the performance of grouting

materials.

## 3. Effects of different temperatures on properties of geopolymer grouting materials

The properties of geopolymer grouting materials are obviously different with different curing methods. The curing method will affect the hydration of geopolymer grouting cementitious materials, and then affect the development of properties. Most scholars generally adopt standard curing methods, but in order to cope with different engineering conditions, more and more scholars try to study the influence of different curing methods on the properties of grouting cementified materials. Panjasila et al [15] studied that the flyash base polymer was exposed to high temperature (200℃, 400℃, 600℃, 800℃, 1000℃, 1200℃) to test its compressive strength and microstructure. Ping et al[4] studied the compressive strength and other properties of flyash-metakaolin base polymer grouting material under the condition of high temperature with alkali initiator (sodium silicate mixed with sodium hydroxide solution). Mongkhon et al[16] studied the performance of fly ash mixed with ordinary Portland cement at curing temperatures of 20℃, 35℃ and 50℃. Kornnika et al [5] studied the microstructure and compressive strength of geopolymer under alkali excited metakaolin cement (sodium silicate and sodium hydroxide) at 23℃ and 60℃. The results show that the microstructure of the samples at high temperature is more compact and the strength is higher, and the setting time and shrinkage rate of the samples decrease with the increase of metakaolin substitute material. Rıdvan and Narmluk et al [17-22] studied the curing temperature and curing time. Rıdvan studied the performance test of metakaolin mixed with fly ash under curing temperature of 60℃, 80℃, early curing time of 2h, 4h, 24h, and then standard curing for 7d. The experiment found that the strength of metacolinite-fly ash base polymer (mass ratio 4:6) in the early curing time 2h and temperature 60℃ was higher than that of Mustaf et al [10] studied that under the activation of alkali activator (sodium silicate and sodium hydroxide mixture), the fly ash base polymer was cured at 50℃, 60℃, 70℃ and 80℃, respectively. The compressive strength was tested for 7 days. The results show that the compressive strength of fly ash base polymer reaches the highest at 60℃. It can be seen that the ambient temperature has a great influence on the setting time of geopolymer. Figure 1 [10] shows the influence of temperature on the compressive strength of fly ash base polymer. When the temperature rises from 30℃ to 60℃, the geopolymer compressive strength increases rapidly. As the temperature continues to increase, the geopolymer compressive strength decreases sharply. It can be seen that geopolymer compressive strength is greatly affected by temperature, and suitable temperature conditions are conducive to the rapid occurrence of geopolymer hydration and polymerization reaction, but too high temperature will have adverse effects on geopolymer, thus reducing the strength of geopolymer. Therefore, according to different engineering conditions, reasonable selection of raw materials, maximize the use of the nature of raw materials, has reached the optimal state.

Mo et al [22] carried out scanning electron microscopy tests on the early curing products of metakaolin base polymer at different temperatures, and the tests showed that under low temperature curing, metakaolin particles dissolved slowly, geopolymer gel grew slowly, and geopolymer samples were still gelatinized and wet. With the increase of curing temperature, the dissolution degree of metakaolin particles will be increased and the formation of hard structures will be accelerated, especially in the early stage of geopolymer reaction. Therefore, the compressive strength of geopolymer samples at high temperature is higher than that of samples at low temperature. Figure 1 shows the SEM figure of early metakaolin base polymer at different temperatures. Tian et al[5] studied the microstruc-ture of copper tailings base polymer at different tempera-tures, and the test showed that moderately elevated curing temperature promoted the dissolution of aluminosilicate and uniform dispersion of gel, resulting in the bridging of the gap between interfacial transition zones, thus enhancing the compressive strength. Excessive curing temperature damages the gel structure and causes the gel to shrink and dehydrate, thus reducing the compressive strength.

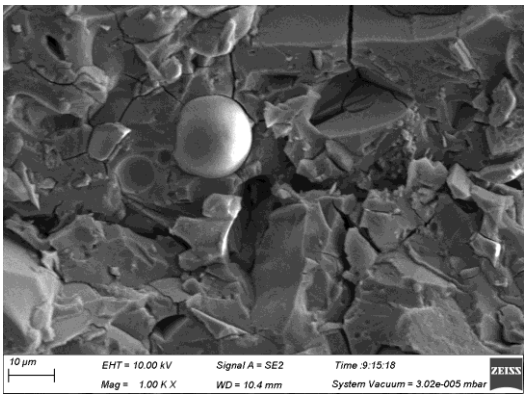


**Figure 1.** SEM diagram

## 4. Conclusion

With the development of China's infrastructure construction, the demand for shield synchronous grouting reinforcement, road trenchless grouting reinforcement and tunnel surrounding rock grouting reinforcement, etc., geopolymers grouting material as environmental protection material to replace high energy consumption cement-based grouting materials is very important practical significance. Geopolymer used in grouting has the advantages of low energy consumption and economic and environmental protection, its application and promotion are in line with the concept of sustainable development of China.

In this paper, the effects of aluminosilicate raw materials, the type and modulus of alkali activator, the fineness of aluminosilicate raw materials, the ratio of liquid to solid on geopolymer grouting cementing materials and the effects of different temperatures on the properties of geopolymer grouting materials are summarized and analyzed. It is concluded that temperature plays an important role in geopolymer grouting materials. Proper temperature can not only enhance the strength of geopolymer materials, but also reduce the setting time, etc., and also has a certain influence on the microstructure of geopolymer. Reasonable selection of geopolymer materials under temperature conditions to meet the requirements of geopolymer grouting materials under different engineering conditions.

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