Properties Analysis of Red Mud Base Polymer Based on Simple Mass Core Method

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Abstract. Because of the strong alkalinity and large amount of heavy metals in red mud, many countries have paid more attention to red mud. According to the traditional treatment method, an innovative scheme is proposed in this paper, which uses red mud (RM), ground granulated blastfurnace slag (GGBS), fly ash (FA) and coal gangue (CG) to produce a new type of low carbon, environmental protection and wide application scenarios geoppolymer (RSF+C). In this paper, the simple centroid design method is used to optimize the ratio of terpolymer, and the mechanical properties of RGF+Cs are analyzed by uniaxial compression. The strength formation mechanism of RGF+Cs was revealed by TG-DTG and SEM-EDS techniques. The results show that the optimal UCS of RSF+Cs is 5.25MPa. RM provides a positive alkaline environment for GGBS and FA, but excess RM can cause UCS to decline. A large amount of C-A-S-H and C-S-H gels were found in the samples by microscopic analysis.

Keywords: Red mud; Mechanical properties analysis; Mechanism analysis

1 Introduction

Red mud is the main solid waste in the Bayer process of aluminum extraction from bauxite, and approximately 1.5 to 2 tons of red mud are produced globally for every ton of aluminum produced[1,2]. With the continuous growth of bauxite mining, the production of red mud also shows a trend of increasing year by year, which causes severe challenges for its treatment and disposal[3-5]. Therefore, it is particularly urgent to seek innovative treatment and resource utilization of red mud. At the same time, other solid wastes such as fly ash, coal gangue and blast furnace slag have similar problems[6,7], such as heavy metal pollution, large volume and high disposal costs. However, these solid wastes are not only an environmental burden, their respective physical and chemical properties also provide possibilities for their comprehensive utilization in multiple application fields. In recent years, many scholars have devoted themselves to exploring the application potential of red mud in the fields of building materials and environmental governance。 Li et al. [8] studied that mechanical activation can not only effectively activate red mud, but also effectively improve the reaction between waste incineration ash and red mud. When 14% sodium silicate was added to

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reached 12.75 MPa on day 28. Zhang et al. [9] used CaO to activate the tribauxite, hydrobauxite and silica components in RM, and the hydration reaction produced gel-like aluminum to replace Tobermolite (OH)O·$5H_2O$), which ensured the improvement of the strength in the later stage. At 28 days of age, the unconfined compressive strength of red mud based cementing material with CaO content of 25% is the highest, reaching 2.19 MPa.

In order to improve the properties of red mud (RM) based cementing material and improve the utilization of solid waste, a new green geopolymer material was proposed in this study. Due to the high specific surface area of red mud, it can improve the bonding force and compactness of the mixture, and can provide an alkali environment to promote the pozzolanic reaction of other solid wastes, while fly ash (FA) and ground granulated blastfurnace slag (GGBS) can improve the fluidity and strength. A new kind of green geopolymer RGF+C was prepared by combining coal gangue (CG) with reasonable ratio and making full use of these by-products.

2 Test Materials and Methods

2.1 Experimental Materials

In this study, red mud (RM), ground granulated blastfurnace slag (GGBS) and first grade fly ash (FA) were selected as cementing materials, and RM was provided by Liaocheng Jiangbei Shuicheng Yi Casting Material Factory. FA from Henan Borun Casting Material Co., LTD.; GGBS from Gongyi City Longze water purification materials Co., LTD. Spontaneous combustion coal gangue (CG) is taken from Fuxin Mining Group as aggregate. The alkali activator uses sodium hydroxide particles with a purity of 99%. Urban tap water is the only water source for this experiment.

2.2 Test Methods

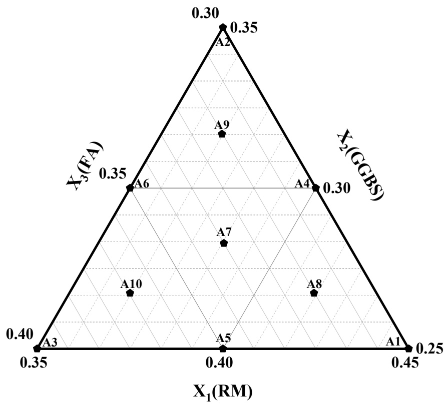


Fig. 1. The overall design point based on the three-component enhanced simplex centroid hybrid design. (Note: A1 to A10 are sample points for the experiment.)

In this study, the simplex centroid mixture design (SCMD) method was used to analyze the variable response relationship, establish continuous variables and optimize the mixture. A three-component enhanced SCMD was used to evaluate the relationship between different mixtures (RM, GGBS, and FA) and multiple test metrics (Y). The main ingredient RM (X1, %) is used in a range of 35%–45%, GGBS (X2, %) is used in a range of 25%–35%, and FA (X3, %) is used in a range of 30%–40%. As shown in Figure 1, a total of 10 different mixing points are designed. CG is added to RGF to form RGF+Cs, where CG makes up 66% of the total mass.

2.3 Test and Characterization Methods

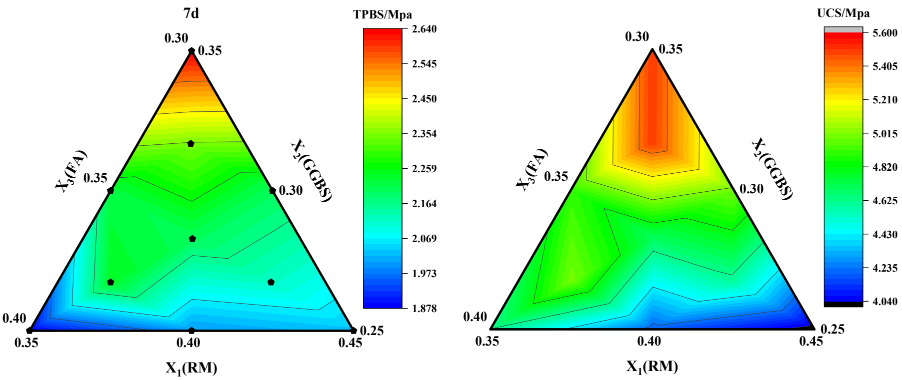
The mechanical properties of RGF+Cs were tested by a 10t hydraulic servo tester in displacement control mode. The loading rates were set to and 1mm/min respectively, and the three-point bending strength and uniaxial compression strength of RGF+Cs samples were measured at day 7 and day 28. The testing procedure conforms to the Chinese GB/T17671-1999 and GB/T50081-2016 standards.

3 Results

3.1 Mechanical Properties Analysis of RGF+Cs

It can be seen from Figure 2 that in this study system, minerals in GGBS are relatively stable in long-term reaction and can provide lasting strength support. Gels generated by GGBS under alkaline conditions continue to develop and cure during curing, usually showing good strength growth under long-term curing conditions. Excessive RM can cause UCS to decline, adversely affecting UCS strength. Because the reactivity of red mud is relatively low compared with GGBS and FA, although it contains some silica-aluminum components, the reaction degree is limited, in addition, Fe2O3 and other components in red mud will also form substances that are not conducive to the development of strength in RGFs volcanic ash reaction. The UCS of RGFs is negatively correlated with the FA content. Excessive incorporation of fly ash will dilute the active component in the geopolymer and reduce the reaction chance of other active components with alkaline activators, thus affecting the formation of gels. Too much FA will also make the gel reaction incomplete, resulting in structural instability of the gel network, which will affect the structure and strength of RGFs.

Although fly ash contains a certain amount of reactive silica-alumina minerals, its overall reactivity is low compared with other materials. This low activity results in the failure of fly ash to react quickly during the early curing of RGF+Cs, thus affecting the early strength.



(a) (b)

Fig. 2. Contour map of the unrestricted compressive strength of RGF+Cs.

3.2 Thermogravimetric Analysis

Figure 3 shows the thermogravimetric analysis results. The weight loss peak observed on the DTG curve near 40°C is mainly attributed to the co-dehydration of weakly bound water of C-A-S-H and C-S-H gel. After 100°C, all the above substances volatilate, which is also confirmed by an obvious thermogravimetric step. The further weight loss at 120-350°C may be related to the removal of structural water from $Ca(OH)_2$, and the subsequent weight loss (550-700°C) mainly comes from the decomposition of CaCO3, and the slow weight loss at the last stage is related to the decarbonization of calcium carbonate in the sample. At 900°C, A large number of residual components exist, and the residual components may be quartz and uncarbonized calcium silicate (aluminum) hydrate (C-(A)-S-H) gel[10].

At 40-100°C, the mass loss of four groups of samples showed that the production of the main hydration product (gel) of RGF-9 was greater than that of the remaining three groups, which is consistent with the results of UCS analysis. The mass loss of the four groups of samples in the range of 120-350°C indicated that the total amount of $Ca(OH)_2$ was not high. As a reaction intermediate, $Ca(OH)_2$ reacted with silica and aluminate with high activity to form hydration products, indicating that the reaction degree of each group was high. In the range of 550-700°C, the mass loss of the four samples is similar, but it can be seen from the DTG that the reaction of RGF-9 is involved in more OH^- and less carbonization. This reflects the synergistic effect between RM, GGBS and FA at this ratio, which improves the hydration degree of the cemented material.

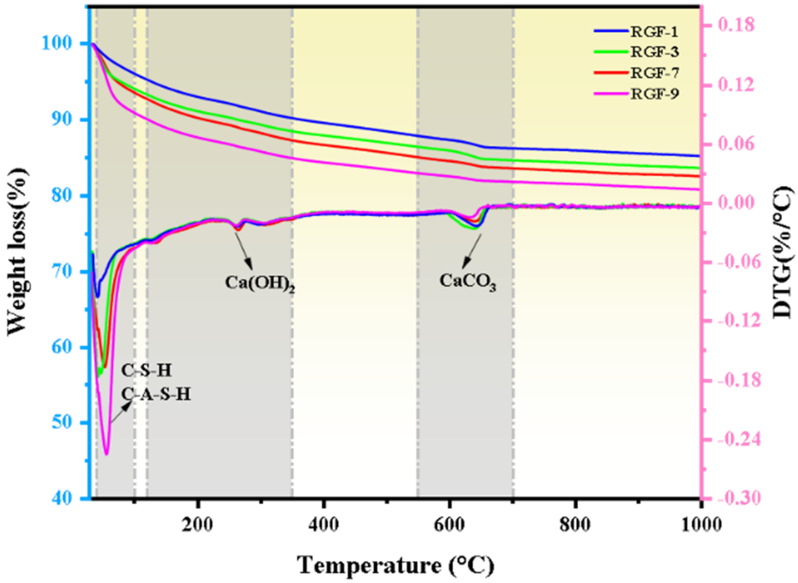
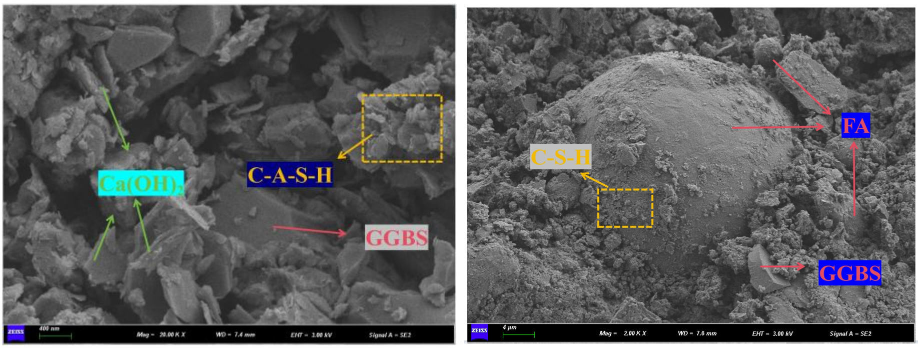


Fig. 3. TG and DTG curves of samples at 28 days.

3.3 SEM-EDS Analyze



(a) (b)

Fig. 4. SEM results of RGF+C-9.

Fig. 4. shows the SEM results of RGF+C-9. It can be found that there is A large amount of C-(A)-S-H gel in the sample, and a large amount of flocculant is formed on the surface of FA particles. However, the hydration effect of FA itself is not ideal, which is also the reason why the compressive strength of the sample is greatly reduced after the addition of FA. At the same time, the volcanic ash material provides the matrix structure, reaction glass phase and nucleation site, which affect the formation of alkali activation products. This conforms to the design principle of the ternary base activated gelling material and confirms the results of macroscopic properties.

4 Conclusion

(1) In this paper, several materials including red mud, slag, fly ash and coal gangue are used to jointly produce a new type of low-carbon, environmentally friendly and widely used geopolymer (RSF+C).

(2) The simple centroid design scheme was adopted in this paper, and excessive RM would lead to UCS decline and adversely affect UCS strength. Excessive incorporation of fly ash will also dilute the active ingredients in the terpolymers and reduce the reaction chance of other active ingredients with alkaline activators.

(3) From the microscopic experiment, it can be found that the synergistic effect between RM, GGBS and FA improves the hydration degree of the cemented material.

(4) On this basis, we can further explore the durability and application of alkali activated coal measure solid waste based green filling materials. The results of this study are helpful to the development of green filling materials based on solid waste in coal measures, so as to promote the resource utilization of solid waste in coal mines.

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