Study on Preparation and Properties of Unburned Ceramsite With Steel Slag

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Abstract. Using steel slag, fly ash and clay as physical materials, cement, expanded perlite and methyl cellulose as additives, the raw materials were ground, bullied, aged, cured and prepared into lightweight and high strength ceramsite. The effects of steel slag, fly ash, clay and cement on the packing density and cylinder compression strength of unburned ceramsite were studied by single factor variable analysis, and the optimum mixing ratio of hot stuffing steel slag, air-quenched steel slag and other raw materials was also studied. Finally, the ratio of fly ash to clay is 40:50:10 and the optimum content of cement is 10%. The content of expanded perlite is 2%. The content of methyl cellulose is 1%. The accumulation density of unburned ceramsite is 943.5kg/m³, and the compressive strength of the tube is 8.153 MPa. Through scanning electron microscope (SEM) and energy spectrum analysis, the microstructure of ceramsite has many small and irregular vitreous composition, most of which are composed of silicate and carbonate. Loose and porous cellular structure is formed between vitreous body and vitreous body, which leads to small volume density of ceramsite.

1. Introduction

Ceramsite, as a kind of artificial lightweight aggregate, has the characteristics of light weight, good fire resistance, good earthquake resistance and strong adaptability of raw materials. It is widely used in wall materials [1], backfill materials [2], constructed wetlands [3] and so on. However, the traditional ceramsite is made by burning or sintering process [4], which has high production cost and serious environmental pollution. The preparation of unburned ceramsite from cementitious materials has become a development direction of ceramsite.

Steel slag is a kind of solid waste material with cementitious property. Xiang Xiaodong [5] prepared steel slag unburned ceramsite by washing ball mud with slag water in WISCO, and obtained higher tube pressure strength. Therefore, it is an important work to study the preparation technology of high strength lightweight steel slag unburned ceramsite.

2. Experimental raw materials

The main raw materials of this study are steel slag, fly ash, clay, cement, expanded perlite, grade A cellulose and so on.
2.1. Steel slag
The steel slag used in this study is hot stuffy steel slag and air-quenched steel slag, both of which come from an iron and steel enterprise in Ma-an-shan City.

Compared with hot bored steel slag, the particles of air-quenched steel slag are smaller and more uniform, and rust exists on the surface. However, the particles of hot stuffy steel slag are uneven and the large particles are relatively large. When these two kinds of steel slag are used as ceramsite, the grinding time of air-quenched steel slag is shorter than that of hot stuffy steel slag, and the grinding property is better.

Then, the steel slag of different treatment processes is ground into steel slag powder with a particle size of about 200 mesh through a trial mill, and the chemical composition is analyzed by XRF method. See Table 1 for the results.

| Chemical composition /wt% | CaO | SiO₂ | Al₂O₃ | MgO | Fe₂O₃ | MnO | P₂O₅ |
|---------------------------|-----|------|-------|-----|-------|-----|------|
| Air quenched steel slag   | 34.93 | 12.87 | 2.85  | 4.79 | 23.46 | 2.22 | 2.52 |
| Hot stuffing steel slag   | 33.79 | 13.81 | 2.76  | 3.60 | 23.86 | 2.14 | 2.51 |

It can be seen from Table 1 that the chemical composition of steel slag obtained by the two different treatment processes is very similar, which indicates that the chemical composition of steel slag is changed little by the treatment process of steel slag. As can be seen from Table 1, the chemical composition of steel slag is mainly CaO, SiO₂, Fe₂O₃, while the composition of Al₂O₃ is relatively small. From the triangle rule of composition in making ceramsite, it is necessary to increase the substance containing Al₂O₃.

2.2. Fly ash
The fly ash used in this experiment is derived from a coal-fired power generation enterprise in Maanshan, with an average fineness of 43 um, a density of 2.4g/cm³ and a water content of 0.5% XRF analysis is carried out on the fly ash, the composition of which is shown in Table 2.

| Chemical composition | SiO₂ | Al₂O₃ | CaO | Fe₂O₃ | K₂O | TiO₂ |
|----------------------|------|-------|-----|-------|-----|------|
| Mass content/%       | 53.69 | 33.01  | 4.02 | 3.45  | 2.10 | 1.17 |

2.3. Other materials
The clay used in this experiment is soft kaolin, which is produced from Jingdezhen, Jiangxi. The cement used is P.O 42.5 Portland cement, which is produced from Yangchun Cement Co., Ltd. The perlite used is from the Zhongsen Perlite Application Company in Xinyang, with a density of 50 kg/m³. The experiment needs to make a ball, so the particle size of the expanded perlite has a certain requirement, and the grain size of the expanded perlite needs to be ground into powder with a particle size of 200 meshes. The grade-A cellulose used is analytically pure, and is produced from the Tianjin Damao Chemical Reagent Factory.

3. Experimental equipment and method
3.1. Experimental installation
The granulator used in this experiment is mainly variable speed ball forming machine, the model is BWD0-17-0.75, from Hangzhou Shenfei Gearbox Co, Ltd, and the cylinder pressure strength test equipment is pressure testing machine TYE-300B, from Wuxi Jianyi instrument Machinery Co. Ltd.
3.2. Empirical method
The preparation process of unburned ceramsite is as follows: first, the prepared hot stuffy steel slag and air-quenched steel slag are put into the drying box to dry, and then they are ground into powder with a test mill, and the required steel slag powder, fly ash, clay, cement and additives are weighed according to the proportion needed in the experiment [6]. Then mix the measured raw materials and pour them into a concrete mixer to mix them evenly. The mixed raw materials are made by spraying water fog with variable speed forming machine. The rotating speed of the variable speed ball forming machine is kept at 18.35 r/min and the inclination angle is kept at 45°. The ball is preserved by natural conservation. After the ceramsite is hardened, the ceramsite is finished with the corresponding standard screen. The ceramic products with qualified particle size were obtained, and the properties of ceramsite products were tested and analyzed.

3.3. Ceramic particle performance test method
The compressive strength and packing density of ceramsite were determined according to GBT17431.2-2010.

4. Results and discussions
4.1. Effect of the content of steel slag on the performance of burn-free ceramsite
The total proportion of the temporary steel slag, the fly ash and the clay is 100 percent, the mass ratio of the fly ash to the clay is 1:1, the doping amount of the cement is 10 percent, the doping amount of the expanded perlite is 1 percent, and the doping amount of the steel slag is 20 percent, 40 percent, 60 percent, 80 percent and 100 percent in sequence.

The accumulation density and tube compression strength of ceramsite in the above five groups were measured respectively [7]. The results are shown in Fig. 1 and Fig. 2.

![Fig. 1 Effect of steel slag content on accumulation density of unburned ceramsite](image)

As can be seen from Fig. 1, both the wind-quenched steel slag and the hot-bored steel slag ceramsite, the bulk density thereof is increased with the increase of the content of the steel slag. when the content of the wind-quenching steel slag is more than 60 percent, the stacking density of the burning-free ceramsite is more than 1000 kg/m³, The sintering-free ceramsite prepared by the invention has the bulk density of more than 1000 kg/m³, and the burning-free ceramsite does not belong to the light-weight ceramsite series at the time.
As can be seen from Fig. 2, there is a matching relationship between the steel slag and the fly ash and the clay. When the proportion of the steel slag and the clay is 4:3:3, the prepared burn-free ceramsite cylinder has the highest pressure strength and is obviously higher than that of the baking-free ceramsite made of other proportions. The reason for this is that the composition structure of steel slag, fly ash and clay and the properties of the powder are different, and the particle size distribution of the powder is different. When the three are used in combination, the particles with different particle size distribution may form a continuous size fraction, thus being beneficial to the formation of more excellent physical and mechanical properties.

4.2. Effect of the ratio of fly ash to clay on the properties of non-fired ceramsite

In this part, air quenched steel slag is selected. The added amount of fixed steel slag is 40%, and the total proportion of controlled fly ash and clay is 60%. The admixture of selected fly ash is 50%, 40%, 30%, 20% and 10%, the clay content is 10%, 20%, 30%, 40% and 50%. The cement content is 10% and the expanded perlite is 1%. According to the above-mentioned test scheme, the calcine-free ceramic particles are prepared and cured under natural conditions. See Fig. 3 for the test results of the cylinder compressive strength and bulk density of the non-burned ceramic particles.

4.3. Effect of cement ratio on properties of unburned ceramsite

The ratio of fixed steel slag to fly ash and clay is 4:5:1. The cement content is set as 5%, 10%, 15%, 20% and 25% respectively. See from Fig. 4 for the properties of the prepared steel slag burn-free ceramic particles.
4.4. Effect of Admixtures on the Properties of Burned-free Ceramite

On the basis of the previous experiment, it is assumed that the ratio of raw materials is steel slag: fly ash: clay: cement = 40:50:10. Air quenching steel slag is still selected. The dosage of expanded perlite was 1%, and that of grade A cellulose was 1% as the control group. When the effect of expanded perlite on the properties of unburned ceramsite was studied, the content of expanded perlite was increased by 1%, 2%, 3%, 4% and 5%, respectively. The effect of grade A cellulose on the properties of unburned ceramsite can be divided into 0.5%, 1%, 1.5%, 2% and 2.5% respectively. The experimental results are shown in figure 5 and figure 6, respectively.

Fig. 5 Experimental results of determination of properties of unburned ceramsite

Fig. 6 Experimental results of determination of properties of unburned ceramsite
4.5. Micro-cosmic analysis of ceramsite

In this experiment, the ceramsite with the highest compression strength, moderate size and good roundness was selected and analyzed by scanning electron microscope (SEM). The SEM image of the ceramsite is shown in Fig. 7.

From Fig.12, it can be seen that the surface of the ceramsite is formed by the accumulation of a number of small particles. These small particles are in the form of a vitreous body, and there are many air holes between each of the glass bodies [8]. The vitreous body is irregular in shape, most of which are silicate and carbonate and the like, and a loose porous honeycomb structure is formed between the glass body and the vitreous body. This is that the surface and the internal structure of the ceramsite contain a number of air holes which are not uniformly distributed and that each of the pores is rarely in communication with the other air holes, resulting in a smaller bulk density of the haydite. The glass body has a high strength, which is the basis for the strength of the ceramsite.

5. Conclusion

Through the exploration of the raw material ratio and process of the preparation process of steel slag unburned ceramsite, the optimal raw material ratio and preparation process were determined, and the steel slag unburned ceramsite with lightweight and high strength was prepared [9]. The conclusions are as follows:

(1) By using the method of single factor variable, the ratio of steel slag, fly ash to clay is 40:5:10, and the optimum content of cement is 10%.

(2) By using the method of single factor variable analysis, the optimum content of expanded perlite and grade A cellulose is 2% and 1%, respectively. The packing density of unburned ceramsite is 943.5 kg/m³, and the compression strength of cylinder is 8.153 Mpa. the results show that the optimum content of expanded perlite is 2% and the optimum content of grade A cellulose is 1%.

(3) The microstructure of ceramsite consists of many small and irregular vitreous bodies, most of which are composed of silicate and carbonate [10]. Loose and porous honeycomb structure is formed between vitreous body and vitreous body. From the SEM images of ceramsite, it can be observed that the distribution of these pores is not very uniform, and each stomata is rarely connected with other pores, which leads to a small volume density of ceramsite.

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