Effect of Coal Gangue Grain Size on Strength of Foam Concrete

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Abstract—This work shows that the grain size of coal gangue has affects on the strength of foam concrete with coal gangue. Coal gangue was crushed and separated into three grades sand according to the size which were 0.16-0.6mm, 0.6-2.5mm and 2.5-5mm. Then these coal gangue sand was used to manufacture foam concrete with a density of about 850kg/m³. The compressive, flexural strength, water absorption and softening coefficient of coal gangue foam concrete were tested. The results show that compressive strength of foam concrete exhibits a monotonic decreasing while coal gangue content increases and the decreasing rate would accelerate with the increasing of grain size. And the water absorption increased with the coal gangue content and grain size increasing. Small size coal gangue could improve the water absorption resistance. The coal gangue foam concrete is a water-resistant material and the softening coefficient is above 0.85, when the diameter of coal gangue fine aggregate is below 2.5 mm.

1. Introduction
China, the biggest consumer of coal on the earth[1], is facing the pollution of coal gangue. Coal gangue is the major coal mining solid waste. It is a huge threat on ecological environment, causing spontaneous combustion, heavy metal pollution and occupying land[2-4]. According to the published data of the National Development and Reform Commission of China, there are over 2600 giant coal gangue hills in China in 2014[5]. Therefore, comprehensive utilization of coal gangue is becoming important and attractive. The construction industry is a major route for consuming solid waste.

Foam Concrete is a type of cellular lightweight concrete in which air-bubbles are injected using foaming agent and foaming machine[6]. The density varies from 300 to 1800 kg/m³. It has higher compressive strength than aerated concrete and good heat insulation, fire resistance, durability and waterproof.

The purpose of present study is to use coal gangue to produce foamed concrete. Coal gangue was utilized as fine aggregate in foam concrete in this study, and the effect of grain size and dosage on compressive, flexural strength and softening coefficient were tested and discussed.
2. Experimental

2.1. Raw materials
In this experimental, P.O. 42.5 R Portland cement was used as binder, and R means early strength cement. The animal protein was used as physical foaming agent, and polycarboxylate was used as superplasticizer (SP). All raw materials were manufactured in China. Coal gangue came from Wuda coalfield, Inner Mongolia, China, which is the one of the biggest coalfield in China. Coal gangue oxide composition is listed in Table I.

| Oxides   | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | K$_2$O | Na$_2$O |
|----------|---------|-------------|-------------|-----|-----|--------|--------|
| Coal gangue | 63.14   | 19.46       | 2.07        | 1.99| 1.45| 0.4    | 0.08   |

2.2. Methods and mix proportions
Coal gangue was crushed in jaw crusher, then sieved and graded according to the grain size. The three grain size grades sand were 0.16-0.6mm, 0.6-2.5mm and 2.5-5 mm.

The design density of fresh foam concrete was 850 kg/m$^3$. Coal gangue was used as fine aggregate and to decrease the content of binder. The amount of coal gangue replacing cement was 0, 10%, 20%, and 30%. The volume of foam was decided by the design density. Mix proportions of foam concrete are presented in Table II. To avoid the effect of water/cement ratio (W/C) on strength, the W/C is 0.4. The foam was prepared by using foaming agent. SP was added to adjust the workability of fresh concrete to meet the casting requirement.

According to Chinese Standard GB/T 17671-1999 Method of testing cements—Determination of strength, 40mm × 40mm × 160mm quadrangular prism was casted for compressive strength and flexural strength test. The specimens were cured in standard condition and tested at 3d, 7d and 28d. After 28d in standard condition, they were dried until the weight did not reduce in 60 ℃ to test dry strength and were totally soaked in water 1 day to test wet strength.

| Table II. Mix proportions of foam concrete |
|------------------------------------------|
| Cement /kg | Coal gangue /kg | Foam /L | Water /kg | W/C | SP/kg |
| D850-0     | 650              | 0       | 775       | 260 | 0.4  | 0     |
| D850-10    | 575              | 65      | 750       | 230 | 0.4  | 0.5-1*|
| D850-20    | 520              | 130     | 750       | 208 | 0.4  | 0.5-1.5*|
| D850-30    | 455              | 195     | 725       | 182 | 0.4  | 1-2*  |

*Adjusting the content of SP according to concrete workability

3. Results and Discussion

3.1. Compressive and flexural strength
Compressive strength values of the foam concrete with different grain size of coal gangue are showed in Fig. 1. The bar graphs present the compressive strength exhibits a monotonic decreasing while coal gangue content increases at 28d, regardless of grain size. Comparing the influence of grain size, the foam concrete compressive strength with 0.16-0.6 mm reduced mildly, and the value is about 6.8 MPa at 30% replacement; the foam concrete compressive strength with 0.6-2.5 mm reduced too, but when the replacement is 30% the strength is reduced to 5.7 MPa; and the foam concrete compressive strength with 2.5-5 mm reduced rapidly, the value is about 4.9 MPa 30% replacement. Compressive strength with 0.16-0.6 mm and 0.6-2.5 mm are similar while coal gangue content is below 20% and both of them are higher than those with 2.5-5 mm at every class of coal gangue content. It shows that the
decreasing rate of compressive strength would accelerate with the increasing of grain size. But the regulation with content and size is not obvious at 3d and 7d. Maybe the reason is the strength of hardened cement bubbles are low at early age.

Fig. 2 show bar graphs of flexural strength. The flexural strength is different with compressive strength. Coal gangue would lead to the reduction of flexural strength. But the regularity of strength and content is not obvious as compressive strength and the decrease is smaller than that of compressive strength. The strength almost is not reduced with the content of 0.16-0.6 mm coal gangue sand and its content presents a little influence on flexural strength. For 0.6-2.5 mm coal gangue sand, flexural strength reduced when the content increases to 30%. And for 2.5-5 mm coal gangue sand, flexural strength reduced when the content increases to 20%. But the strength is higher than 0.6-2.5 mm coal gangue foam concrete. This is due to the strengthening effect of the big size coal gangue in the fracture interface. Fig. 3 shows the morphology of fracture surface of specimens with 2.5-5 mm. There are some broken grains in the fracture surface. These big size coal gangue aggregate could span multiple bubbles which could enhance the tensile stress.
Fig. 4 shows ratios of compressive strength and flexural strength. The ratio of foam concrete is below the normal concrete. Except the ratio of 2.5-5 mm coal gangue foam concrete decreases obviously at 30%, the ratio has no significant change with the content of coal gangue. The ratio is fluctuated within a range of around 5 between 5.7 and 4.3. The degree of volatility is 14%. When 2.5-5 mm coal gangue is 30%, the ratio reduction is 28%.

Although big size is benefited to flexural strength, the small size coal gangue aggregate is more suitable for producing coal gangue foam concrete due to compressive strength is primary in construction.
3.2. Water absorption

Water absorption of insulation materials will cause the material's thermal insulation performance to be greatly reduced. Therefore, as far as coal gangue foam concrete is concerned, the study of water absorption is very critical. The test results of water absorption are showed in Fig. 4. Water absorption increased with the coal gangue content and grain size increasing. With 10% 0.16-0.6 mm coal gangue, the water absorption is lower than that without coal gangue. Absorbing water amount of most specimens with the coal gangue content below 20% are similar to control specimen. When the content was 30%, the water absorption of 0.6-2.5 mm and 2.5-5 mm specimens are higher than that of control specimen. The broken lines manifest that water absorption increased with the content and the grain size of coal gangue in overall tendency. There are two probable reasons. The one is coal gangue has many interstices, adding more brings more interstices. The other is interstices would reduce when the particle size crushed smaller. This presents that 0.16-0.6 mm is also the better than other two sizes coal gangue and the content should be below 20% when using 0.6-2.5 mm and 2.5-5 mm.
After the insulation material absorbs water, if its water resistance is poor, it will seriously affect the normal service life of the insulation material. The softening coefficient is an important indicator of water resistance properties, and is the ratio of the compressive strength in a water-saturated state to the compressive strength in a dry state.

3.3. Softening coefficient

Figure 4. Ratio of compressive strength and flexural strength

Figure 5. Water absorption of foam concrete with coal gangue

| Coal gangue grain size | Compressive strength | Wet compressive strength | Dry compressive strength |
|-----------------------|----------------------|-------------------------|-------------------------|
| D850-0                | 8.3                  | 7.9                     | 9.1                     |
| D850-10              | 7.9                  | 7.7                     | 8.4                     |
| D850-0.16-0.6mm      | 7.0                  | 6.7                     | 7.6                     |
Figure 6. softening coefficient of coal gangue foam concrete

The compressive strength in a water-saturated state to the compressive strength in a dry state were listed in Table III. And the softening coefficient were shown in Fig. 6. It is shown that the softening coefficient of foam concrete decreases as the particle size of coal gangue increases. Smaller coal gangue grain is better at improving the softening coefficient. The softening coefficient of water-resistant materials should generally be greater than 0.85. Therefore, considering the softening coefficient, it is reasonable that the diameter of coal gangue fine aggregate should be below 2.5 mm.

4. Conclusions
In this present work, the effect of coal gangue grain size on strength of coal gangue foam concrete was studied. The main conclusions are summarized as follows:

- Compared to control specimens, coal gangue would lead to the reduction of strength. The compressive strength of foam concrete exhibits a monotonic decreasing while coal gangue content increases, and the decreasing rate would accelerate with the increasing of grain size. And flexural strength decrease is mild than compressive strength.
- The small size coal gangue aggregate is more suitable for producing coal gangue foam concrete due to the compressive strength, although big size is benefited to flexural strength,
- Water absorption increased with the coal gangue content and grain size increasing. Small size coal gangue foam concrete shows better water absorption resistance. When the content was 10% and grain size was 0.16-0.6 mm, coal gangue could improve the water absorption of foam concrete.
• The coal gangue foam concrete is a water-resistant material and the softening coefficient is above 0.85, when the diameter of coal gangue fine aggregate is below 2.5 mm.

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References
[1] Wenfeng Wang, Weiduo Hao, Zhengfu Bian, Shaogang Lei, Xuesong Wang, Shuxun Sang, Shaochun Xu. Effect of coalmining activities on the environment of Tetraena mongolica in Wuhai, Inner Mongolia, China-A geochemical perspective. International Journal of Coal Geology, vol. 132, pp. 94–102, 2014.
[2] Yanci Liang, Handong Liang, Shuquan Zhu. Mercury emission from spontaneously ignited coal gangue hill in Wuda coalfield, Inner Mongolia, China. Fuel, vol. 182, pp. 525–530, 2016.
[3] Yanci Liang, Shuquan Zhu, Handong Liang. Mercury enrichment in coal fire sponge in Wuda coalfield, Inner Mongolia of China. International Journal of Coal Geology, vol. 192, pp. 51–55, 2018.
[4] Yuguo Wu, Xiaoyang Yu, Shengyong Hu, He Shao, Qi Liao, Yurong Fan. Experimental study of the effects of stacking modes on the spontaneous combustion of coal gangue. Process Safety and Environmental Protection, vol. 123, pp. 39–47, 2019.
[5] Jin Yang, Ying Su, Xingyang He, Hongbo Tan, Youzhi Jiang, Linghao Zeng, Bohumir Strnad. Pore structure evaluation of cementing composites blended with coal byproducts: Calcined coal gangue and coal fly ash. Fuel Processing Technology, vol. 181, pp. 75–90, 2018.
[6] Amritha Raj, Dhanya Sathyan, K.M. Mini. Physical and functional characteristic of foam concrete: A review. Construction and Building Materials, vol. 221, pp. 787-799, 2019.