Experimental Study on Compressive Strength of New Type Volcanic Slag Lightweight Aggregate Concrete and Its Hollow Block

To cite this article: Wang Zheng and Fang Guangxiu 2018 IOP Conf. Ser.: Earth Environ. Sci. 189 032063

View the article online for updates and enhancements.
Experimental Study on Compressive Strength of New Type Volcanic Slag Lightweight Aggregate Concrete and Its Hollow Block

Wang Zheng¹, Fang Guangxiu¹,²
¹Department of Structural Engineering, College of Engineering, Yanbian University, Yanji, China
²Corresponding author
¹137709077@qq.com, ²gxfang@ybu.edu.cn

Abstract. In this paper, the recycled aggregate that is made from light red volcanic slag and abandoned concrete is used as a coarse aggregate, while fly ash and calcined diatomite are used as cementing materials in order to replace part of the cement. The mix proportion of lightweight aggregate concrete made from volcanic slag is designed and tested. A new type of lightweight aggregate concrete hollow block with volcanic slag has been developed by means of the pore structure of the main design, and the revised formula of the compressive strength of the concrete block was obtained by regression analysis of the compressive strength test results. The block has the advantages of having an excellent compressive strength, good thermal conductivity, low cost and so on.

1. Introduction
Concrete is the most important building material in the field of modern engineering, but ordinary concrete has the disadvantages of weight and poor thermal insulation performance. Compared with the ordinary concrete, the lightweight aggregate concrete is a material which has good shock resistance, crack resistance and fire resistance. At present, the lightweight aggregates that have been used in China are mainly composed of volcanic slag, pumice and coal gangue. At present, volcanic slag lightweight aggregate concrete has also achieved certain research progress and engineering practice in China [1], Jilin Province volcanic slag reserves rank first in the country, of which light volcanic slag accounts for 30 million m³.

Experts and related scientific research institutions have carried out a series of experimental studies on volcanic slag concrete and hollow blocks. Such as: Alaettin Kilic et al [2], proposed that single or mixed silica fume can improve the flexural strength of volcanic ash lightweight aggregate concrete, and silica fume can also reduce the wet density and dry density of concrete; Yue Zhixin et al [3], proposed that calcined diatomite can significantly improve the late strength of concrete, and the early strength decreases with the increase of diatomite content.

By analyzing the literature research of volcanic concrete, it is found that the method of improving the strength of volcanic slag concrete by replacing part of cementitious materials with calcined diatomite is little. The innovative design of volcanic slag lightweight aggregate concrete mix ratio is carried out, which is studied to the ratio of double-mixed fly ash and diatomite to replace cement, meanwhile, the ratio of recycled aggregate to replace natural coarse aggregate on the compressive strength of volcanic slag concrete. The regression analysis of Origin8.5 is used to sum up...
the regulation of compressive strength development. The hollow block is cast by using the group of optimal mix ratio. The compressive strength of the block was measured by pressure machine after 28 days, and using the ANSYS to simulated the process. Finally, the experimental values was compared with the theoretical values, and proposed a formula with correction coefficient on the strength of the new volcanic slag lightweight aggregate concrete hollow block.

2. Experimental materials

90 concrete specimens of 150mm × 150mm × 150mm and 10 hollow blocks of 390mm × 190mm × 190mm are made in this experiment. The main experimental materials shown as follows:

1) Natural coarse aggregate: After crushing, the red volcanic slag particle size is 5-10mm, the water absorption is 22%. The dry accumulation density is 1042kg/m³;
2) Natural fine aggregate: Yanji river sand with diameter below 5mm;
3) Recycled coarse aggregate: waste concrete samples from Yanji construction site were separated by jaw crusher. In this experiment, the diameter range of regenerated coarse aggregate was 5-10mm.
4) Cement: PO42.5R ordinary portland cement, produced from Jilin Yatai Cement Co., Ltd.
5) Diatomite: Diatomite filter aid powder, produced from Linjiang Tianyuan Catalyst Co., Ltd.
6) Fly ash: Grade I fly ash of Chaoyang building materials in Yanji city;
7) Water: Yanji city tap water;
8) Additives: The effective polycarboxylic acid superplasticizer mother liquor was produced by Yanji Fangsheng Building Materials Co., Ltd.

3. Mix design and strength of volcanic slag lightweight aggregate concrete

According to code [4], lightweight aggregate concrete with CL20, density grade 1800 is designed. The design strength of lightweight aggregate concrete hollow block is MU10.0, and the hollow rate is 40%. The loose volume method is used to calculate sand rate in this design.

3.1. Trial strength of concrete

In order to ensure that the test strength of lightweight aggregate concrete can meet the requirements of compressive strength, the design strength is confirmed according to formula (1):

\[f_{cu,0} = f_{cu,k} + 1.645\sigma\]  

In this formula: \(f_{cu,0}\) — Test strength of lightweight aggregate concrete (Mpa); \(f_{cu,k}\) — Standard value of cube compressive strength for lightweight aggregate concrete (Mpa); \(\sigma\) — Standard deviation of strength for lightweight aggregate concrete, and value according to table 1.

| Strength grade of concrete | Lower than CL20 | CL20–CL35 | Higher than CL35 |
|---------------------------|-----------------|-----------|------------------|
| \(\sigma\)                | 4.0             | 5.0       | 6.0              |

The value of \(\sigma\) is 5.0, \(f_{cu,0} = 20 + 1.645 \times 5.0 = 28.23\) (MPa)

3.2. Cement content of concrete hollow block

According to the code [5], the cement dosage is 370-440 kg/m³. The fluidity of concrete is poor when the trial mixing value is 390 kg/m³. After increasing the cement content by 5%, the slump of concrete is 5 mm, which meets the initial design requirements of slump. That is, the cement dosage is 419.5 kg/m³.

3.3. Water cement ratio and water consumption

The concrete of the block must be dry and hard, the slump is 0-10 mm, the ratio of clean water to cement can be selected in 0.30 ~ 0.42, and the ratio of clean water to cement is 0.41 in this design. The water consumption was 170 kg/m³;
3.4. Sand coarse aggregate ratio and amount of coarse aggregate

According to specification [6], ordinary sand is selected to calculate in sand ratio, and using the loose volume method to calculate it. As shown in tables 2, the sand rate used in this test is 40% and the total volume of coarse aggregate is 1.3m³.

| Fine aggregate variety | Sand ratio (%) | Gross volume of coarse aggregate (m³) |
|------------------------|---------------|--------------------------------------|
| Light weight sand      | 35-50         | 1.25-1.50                            |
| Ordinary sand          | 30-40         | 1.10-1.40                            |

The volume of coarse aggregate is 0.9m³, and the volume of fine aggregate is 0.4m³. According to the formula of aggregate accumulation density and mass, the amount of fine aggregate is determined as 623kg/m³ and the amount of coarse aggregate is 701.36kg/m³.

4. Experimental process and results

In this experiment, lightweight aggregate concrete was designed to strength CL20 and the density is grade 1800. VC group used 100% natural red volcanic slag as coarse aggregate. RC1 used 30% regenerated coarse aggregate instead of red volcanic slag while RC2 used 40% of that.

After trial mixing, the mix ratio is adjusted according to the slump and fluidity of concrete, and the final match has shown in the table 3 (unit: kg/m³). 90 concrete specimens of 150mm × 150mm × 150mm were made and the compressive strength of the concrete was measured for 3 days, 7 days, and 28 days, the average compressive strength of specimens in different age has shown in table 4.

5. Data analysis with Oringin8.5

Use the software Origin8.5 to draw the experimental data into a broken line diagram, and the regression equations have been shown in figure 1, 2 and 3.
In Figure 1, the compressive strength of concrete increased with the increasing of the proportion of diatomite. When the content of diatomite is 5%, the compressive strength of concrete is the highest in each period, and the 28d compressive strength was 26.58 Mpa.

In figure 2, it can be seen that the compressive strength of the concrete with diatomite content of 5% was lower than that in the other two groups, but the compressive strength of the concrete with 5% diatomite was lower than that of the other two groups. At 8 days, the strength of concrete is higher than that of concrete with diatomite content of 0. In addition, the compressive strength of concrete with 3% diatomite content reached the highest value of 28.80 MPA in the three groups.

From figure 3, it can be concluded that the changes of diatomite content, compressive strength and age were similar to those of the first group. The compressive strength of diatomite reached the maximum value of 28.06Mpa at 28 days when the diatomite content was 5%.

The strength of volcanic slag concrete can be improved by replacing natural volcanic slag with 30% recycled aggregate, which is due to the low strength of volcanic slag aggregate itself and the insufficient reaction between aggregate and cementite. In addition, the particle size of recycled aggregate is small in this experiment, which reduces the probability of microcracks in concrete. With 30% recycled aggregate instead of volcanic slag, the later strength of volcanic slag concrete can be improved by adding diatomite. When the content of diatomite is 3%, the compressive strength of concrete reached the 28.80Mpa, which is the highest among all groups.

6. Compressive strength test and finite element analysis of hollow Block

6.1. Design of the hollow block
According to the study [7], it is designed that the outer wall thickness of the concrete block is 25mm, the thickness of the rib wall is 30mm and 25mm, and the thermal resistance can be increased by increasing the arrangement of holes and staggered holes in the concrete hollow block [8].

The size and the mould of block have shown in figure 4 and 5.

6.2. Compressive strength test of hollow block
The strength test of block is carried out according to the test method of small hollow concrete block. 5 blocks with the most complete block form are selected for test, as shown in figure 6.
The crack appeared on the left costal wall of the top in early period, with the increasing of the load, longitudinal cracks appear on the top of the block. The cracks gradually develop from the middle of block to the two sides. When the test load reaches 70% of the limit load, the lower surface of the block fell off and there was an obvious noise. Finally, due to the widening of vertical cracks, the block is destroyed, which takes less time, and the maximum width of the crack reaches 2mm. The results of compressive strength have shown in table 5.

### Table 5. Compressive strength of cinder concrete hollow block

| Number of block | No.1  | No.2  | No.3  | No.4  | No.5  |
|-----------------|-------|-------|-------|-------|-------|
| $\sigma_{bc}$   | 11.83 | 12.74 | 10.67 | 10.56 | 11.85 |

* a limit value of compressive strength

According to the average compressive strength of 5 blocks shown in the above table, the compressive strength of the block is 11.53 MPa. According to the comparison between the measured compressive strength value and the theoretical value obtained from the empirical formula, the correction coefficient $\alpha = 0.89$ is obtained. The relationship between the compressive strength of the new volcanic slag hollow block and the concrete cube test block is as follows:

$$ R_k / R_c = (0.9577 - 1.129K) \cdot \alpha $$

(2)

In formula (2): $R_k$ is the compressive strength of small concrete hollow block; $R_c$ is the compressive strength of concrete cube test block; and $K$ is the hollow rate of concrete hollow block.

### 6.3. Analysis of ANSYS finite element software

Create solid65 unit in ANSYS software. The elastic modulus of the volcanic slag lightweight aggregate concrete is $159 \times 10^2$ MPa, the Poisson's ratio under compression is 0.2, and the density is 1955 kg/m³. In the course of loading, it is only necessary to constrain all the degrees of freedom in the bottom plane of the model.

---

(a) Frontal crack  
(b) Lateral crack

Figure 6. Cracks in blocks

---

(a) Axial direction  
(b) short side direction  
(c) long side direction

Figure 7. Stress Clouds of Hollow Block

In the process of loading, the stress distribution area increases gradually with the increase of load. When the load is 10 MPa, the stress distribution area has developed to most areas, the maximum stress value is 12.848 MPa, which meets the compressive strength requirement of MU10.0 block. It can be seen from the diagram that most areas of the block have uniform force, stress concentration appears at the bottom of both sides, cracks begin to appear and gradually appear diagonal damage from top to bottom, which is basically consistent with the development track of cracks in the experiment.
According to the failure effect, the block goes through elastic, elastic-plastic and plastic failure stages under uniform load. The failure of block is from the linear elastic stage of small load to nonlinear stage, and finally to complete broken.

7. Conclusion
Based on the analysis of the test results of the concrete blocks with the origin software, the regression equation of each age and strength of the volcanic slag concrete was obtained. Calcined diatomite is able to rapidly improve the compressive strength of the slag concrete at the later stage of curing. The way of replacing the cement with fly ash and calcined diatomite can enhance its compressive strength.

A new type of hollow concrete block with volcanic slag is designed. The outer wall thickness of the concrete block is 25 mm, the thickness of the rib wall is 30mm, the number of holes is determined as three rows and the thickness is 20 mm,20 mm,50 mm, respectively. The concrete hollow block is arranged by increasing the number of holes and staggered holes.

Through the cube compression test of the concrete, the mixture ratio of the compressive strength to 28.80Mpa is selected in order to make a hollow block, and the compressive strength test is carried out after curing. The test results show that the compressive strength of the block meets the requirements of CL20 lightweight aggregate concrete as well as the compressive strength of MU10.0 block. Based on the experimental data and the theoretical values that are calculated from the empirical formula, the concrete strength design formula \( RK / RL = (0.9577-1.129K) \alpha \) is put forward.

Acknowledgments
In this paper, the research was sponsored by the Key projects of the science and technology development plan from Science and Technology Department of Jilin Province (20170204032SF)

References
[1] Yang Donglin, et al. Research and Application of volcanic Slag lightweight aggregate concrete at Home and abroad [J], Building Materials Worldwide 17 / 7: 27-30
[2] Alaettin Kilic,CengizDuran Atis,etal. High'-strength Lightweight Concerte Made with Scoria Aggregate Containing Mineral Admixtures[J].Cement and Concrete Research,2003,33(10):1595-1599
[3] Yue Zhixin, et al. New composite self-insulating block and its masonry strength [D], Master's degree thesis, Yanbian University, 2016
[4] GB 8239---1997, Small hollow concrete block [S]. Beijing: China Construction Industry Press, 1997.
[5] GB 50003--2001, Code for Design of masonry structures [S], Beijing: China Building Industry Press, 2001.
[6] GB/T15229-2011, Lightweight aggregate concrete small hollow block [S]. Beijing: China Construction Industry Press, 2011
[7] Li Jiancheng. Effect of pore shape of concrete Hollow Block on its Thermal Insulation [J].Concrete and cement products 1995 (5): 50-52.
[8] Small-sized hollow block of lightweight aggregate concrete [S]. Beijing: China Construction Industry Press, 2011.