Mechanical Properties of Vitrified Micro Bubbles Recycled Concrete Mixed with Calcined Diatomite

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Abstract. In order to prepare vitrified micro bubbles recycled concrete that meets the requirements of strength, the basic mechanical properties of recycled concrete with different vitrified micro bubbles were tested by adding calcined diatomite. The results show that: Calcined diatomite can fill the macroscopic cracks existing in the recycled coarse aggregate and effectively improve the performance of concrete and enhance the compressive strength of recycled concrete; With the increase of the amount of vitrified micro bubbles, the apparent density, compressive strength, splitting tensile strength and elastic modulus of recycled concrete all show a downward trend. When the amount of vitrified micro bubbles is 100% and the amount of calcined diatomite is 3%, the cubic compressive strength of recycled concrete can reach 32.36Mpa and the apparent density is only 1945kg/m³. Based on the experimental analysis, a linear relationship between cubic compressive strength $f_{cu}$ and axial compressive strength $f_c$ of vitrified micro bubbles recycled concrete is presented.

1. Introduction

In recent years, with the development of the construction industry, a large number of natural sand resources were consumed, but also produced tons of construction waste. How to effectively realize energy conservation and environmental protection and make full use of construction waste has been a hot topic for scholars at home and abroad in recent years. Recycled concrete with glass bubbles is a new type of energy-saving and heat preservation recycled concrete which is mixed with glass bubbles to achieve the original intention of heat preservation and energy saving and turning waste into treasure. Song Xuejiao and Hu Zhongjun [1] found that when the replacement rate of recycled coarse aggregate was 100% and the mixing amount of glass bubbles was 6%, the compressive strength of recycled concrete was 30.3MPa and the thermal conductivity was 0.835W/(m•K). Liang Hao et al. [2] found in the study that the size effect of the specimen had influence on the compressive strength, tensile strength, flexural strength and elastic modulus of the glass bead thermal insulation concrete.

As a kind of siliceous rock, diatomite is mainly composed of SiO$_2$, and its prospective reserves in China will reach more than 2 billion tons. Zhou Zhongyi, Sun Qinghe et al. [3, 4] considered that calcined diatomite has the characteristics of volcanic ash effect and micro-aggregate effect, and applied it to recycled concrete, which has achieved certain results. Yue Zhixin and Li Baishou [5] studied the recycled fine stone concrete and ordinary fine stone concrete with different dosage of calcined diatomite and concluded that the compressive strength of recycled concrete can be improved when the dosage of calcined diatomite is controlled within 3% and the dosage of fly ash is 20%.
Based on this, the research proposes to partly replace cement, calcined diatomite to double mixing fully vitrified beads of recycled coarse aggregate concrete, by changing the content of calcined diatomite and vitrified beads, and comparing with ordinary concrete, studies them impact on cube compressive strength, axial compressive strength, splitting tensile strength, compression of static modulus of elasticity of the vitrified micro bubbles recycled concrete, provides theoretical foundation for practical application of vitrified microsphere heat preservation recycled concrete.

2. Testing program

2.1. Test materials

2.1.1. Cement, fly ash, calcined diatomite. Cement is Ding Lu brand P.O 42.5 type of ordinary Portland cement, performance indicators are in line with ASTM regulations; the calcined diatomite is white ultrafine calcined diatomite with a fineness of 325 mesites produced by Linjiang Tianyuan Catalyst Co., Ltd. which has stable and orderly microporous structure. Its performance indicators are shown in Table 1.

| Properties of calcined diatomite | Fe₂O₃ content /% | SiO₂ Content /% | Specific surface area/ (cm²/g) | Ignition loss /% | Loose density / (g/cm³) |
|----------------------------------|------------------|-----------------|-------------------------------|-----------------|------------------------|
| Fe₂O₃                            | ≤1.5             | ≥92             | 600 thousand                  | ≤0.5            | ≤0.42                  |

2.1.2. Vitrified micro bubbles. Vitrified micro bubbles. Are formed by processing in a high temperature electric furnace of 1200 degrees. They are spherical fine-diameter particles with porous interior and closed surface. The bulk density and water absorption rate of glass microspheres are measured to be 126.5kg/m³ and 48.2%.

2.1.3. Aggregate. Recyclable coarse aggregates adopt Yanji City Quality Inspection Station after the strength of C40 concrete test block, their particle size is 5~20mm; Natural coarse aggregates also adopt the particle size of 5~20mm continuous graded gravel; Fine aggregates are natural medium sand.

2.1.4. Water reducer and water. Water reducing agent adopts polycarboxylic acid high performance water reducing agent, which solid content is 40%; Normal tap water is used for water.

2.2. Proportion design

Since both recycled coarse aggregate and vitrified micro bubbles have obvious water absorption, after absorbing free water, the working performance of concrete will be reduced. Therefore, when calculating the mix ratio, the water absorption of the recycled coarse aggregate and vitrified micro bubbles is also considered. The test controls the fly ash content to 20%, the calcined diatomite content to 0~3%, the replacement rate of recycled coarse aggregate is 100%, and the volume ratio of vitrified micro bubbles to concrete is 0, 60%, 80%, 100%, 120%, etc. 5 proportions, in addition, a group of ordinary concrete was prepared for comparison.

After many trials, it is finally determined that the water-to-binder ratio of concrete is 0.35, the unit water consumption is 165kg/m³, the sand rate is 40%, and the amount of water-reducing agent mother liquor is 0.7% of the cementitious material. The workability of the microbead concrete mixture is good. Table 2 shows the mix ratio design of the 7 groups of concrete.
Table 2. Concrete mix design

| Serial number | Water (kg/m³) | Gelled material | Coarse and fine aggregate | Vitrified beads | Water reducing agent | Coarse aggregate absorbs water | Vitrified beads absorbs water |
|---------------|---------------|----------------|---------------------------|----------------|---------------------|-------------------------------|-------------------------------|
| NC-0-0        | 165           | 380.99         | 92.29                     | 978.77         | 652.51              | 3.32                          | —                            |
| RC-0-0        | 165           | 380.99         | 92.29                     | 978.77         | 652.51              | 3.32                          | 32.3                         |
| RC-0-3        | 165           | 367.14         | 13.85                     | 978.77         | 652.51              | 77                            | 32.3                         |
| RC-60-3       | 165           | 367.14         | 13.85                     | 978.77         | 652.51              | 102                           | 32.3                         |
| RC-80-3       | 165           | 367.14         | 13.85                     | 978.77         | 652.51              | 128                           | 32.3                         |
| RC-100-3      | 165           | 367.14         | 13.85                     | 978.77         | 652.51              | 153                           | 32.3                         |
| RC-120-3      | 165           | 367.14         | 13.85                     | 978.77         | 652.51              | 152                           | 32.3                         |

Note: RC-80-3, RC means vitrified micro bubbles recycled concrete, 80 means the volume ratio of vitrified micro bubbles to concrete is 80%, 3 means the volume ratio of calcined diatomite is 3%, and others are similar.

3. Test results and analysis

The concrete slump and apparent density measured in the test are shown in Table 3. The cubic compressive strength \( f_{cu} \), axial compressive strength \( f_c \), splitting tensile strength \( f_s \) and elastic modulus (E) of concrete are shown in Table 4.

Table 3. Concrete slump and apparent density

| Serial number | Concrete slump (mm) | Apparent density (kg/m³) |
|---------------|---------------------|--------------------------|
| NC-0-3        | 200                 | 2384                     |
| RC-0-0        | 198                 | 2123                     |
| RC-0-3        | 195                 | 2185                     |
| RC-60-3       | 210                 | 2003                     |
| RC-80-3       | 206                 | 1986                     |
| RC-100-3      | 210                 | 1945                     |
| RC-120-3      | 196                 | 1930                     |

3.1. Plastic state analysis

The concrete mixture and slump measurement tests are shown in Fig. 1 and Fig. 2. The prepared recycled concrete with vitrified micro bubbles presents good workability. By the table 4 shows, apparent density of recycled concrete showed a trend of decrease with the increase of the dosage of granular particles, analyze this is mainly due to the density of vitrified micro bubbles is small, with the increase of the content, vitrified micro bubbles per unit volume concrete proportion increase, the recycled concrete density decreased; Moreover, it can be found that when the mixing amount of vitrified micro bubbles is 120%, the apparent density of concrete decreases less than that when the mixing amount is 100%. The reason is that the mixing amount of vitrified micro bubbles is too large, and some of the vitrified micro bubbles lack the coating of slurry and are crushed when the concrete is mixed. When the mixing amount of glass bubbles is 100%, the apparent density of vitrified micro bubbles is only 1945kg/m³, which is about 18.4% lower than that of ordinary concrete 2384kg/m³, and the reduction effect is significant.
3.2. Compressive strength

As can be seen from Table 4, with the curing time of vitrified micro bubbles concrete increasing from 7d to 28d, the compressive strength of specimens in each group increased significantly. The first reason is that both recycled coarse aggregate and vitrified micro bubbles have good water absorption. With the extension of curing time, the water absorbed by them is quietly released, so that the surrounding cement can be fully hydrated, and the strength of nearby cement stone is enhanced, so that the later strength of recycled concrete is improved. The second reason is that calcined diatomite, with a finness of 325 mesh, can effectively fill the cracks of recycled coarse aggregate, and react with the highly alkaline Ca(OH)₂ solution in the cracks to produce C-S-H gel with a low calcium-silicon ratio, giving full play to the effect of volcanic ash and micro-aggregate to repair and heal the cracks, thus improving the compressive strength of concrete; Comparing RC-0-3 with RC-0-0 and NC-0-0, it can also be seen that the modified effect of calcined diatomite and fly ash on vitrified micro bubbles recycled concrete. The 28d compressive strength of RC-0-3 with 100% recycled coarse aggregate replacement rate is 7.4% lower than that of NC-0-0, while the compressive strength of RC-0-0 is 9% higher than that of RC-0-0.

As the content of vitrified micro bubbles increases from 0 to 120%, the cubic compressive strength and axial compressive strength of recycled concrete show a decreasing trend. The analysis is due to the increase in the content of vitrified micro bubbles, whose distribution density in the concrete increases, the particles are easy to form through channels, and the density of the cement stone is also reduced, and finally the compressive strength of the concrete is reduced [6]. When the amount of vitrified micro bubbles is 100%, cube compressive strength of recycled concrete is 32.36 MPa, which can satisfy the requirements of C30 concrete strength grade.

The axial compressive strength of the seven groups concrete increases as the compressive strength of the cube increases. The ratio of $f_c$ to $f_{cu}$ of RC-60-3, RC-80-3, RC-100-3, and RC-120-3 are between 0.80 and 0.83. Compared with NC-0-0 (0.76) and RC-0-3 (0.77), the ratio has improved significantly. The analysis is due to the incorporation of vitrified micro bubbles, which reduces the density of recycled concrete. Under axial compression, the lateral restraint effect of the specimen is weaker than that of ordinary concrete and ordinary recycled concrete, which results in an insignificant increase in compressive strength.
The ratio of $f_c$ to $f_{cu}$ gradually increases with the increase of the content of vitrified micro bubbles in recycled concrete. By sorting and analyzing the test data in Table 6, this paper obtains the linear relationship expression between $f_c$ and $f_{cu}$ of recycled concrete with vitrified micro bubbles, as shown in Figure 3:

$$f_c = 0.6916f_{cu} + 3.9734$$  \hspace{1cm} (1)

The relation formula through the origin of coordinates is:

$$f_c = 0.81f_{cu}$$  \hspace{1cm} (2)

The research results are close to the conclusion in the literature [7], indicating that it is safer to calculate the axial compressive strength $F_c$ of the recycled concrete with vitrified micro bubbles according to the provisions of JGJ12-2006 "Design Rules for Lightweight Aggregate Concrete Structures" [8].

3.3. Splitting tensile strength

Figures 4 and 5 show that the recycled concrete splitting tensile strength and compressive strength are on the decline with the increase of dosage of vitrified beads. Compared with RC-0-3, when the contents of vitrified micro bubbles are 60%, 80%, 100% and 120%, the compressive strengths are reduced by 11.9%, 15.7%, 19.9%, and 31%. The split tensile strengths have been reduced by 14.5%, 20.6%, 28%, 40.9%, the decline was even more dramatic, main reason lies in the vitrified microsphere size dosage increased, because of its porous nature, which decreases the density of concrete and increases the internal porosity, under uniaxial load, it is easy to form stress concentration, and along with the augment of vitrified microsphere size, the stress concentration phenomenon is more obvious, eventually led to the splitting tensile strength decreased obviously.

3.4. Modulus of elasticity under static compression

As can be seen from Fig. 6, the elastic modulus of recycled concrete decreases gradually as the mixing amount of vitrified micro bubbles increase from 0% to 120%. Compared with the NC-0-0 group, RC-0-0 decreased by 13.2%, and RC-0-3 only decreased by 8.9%, which was not obvious, which was consistent with the conclusion obtained from the comparison of the compressive strength of the two, which again confirmed the modification effect of calcined diatomite on recycled concrete. However, RC-60-3, RC-80-3, RC-100-3 and RC-120-3 are reduced by 19.6%, 23%, 28.5% and 32.8% respectively, the reason is that the vitrified micro bubbles are porous structures, the larger the content, the higher the porosity in recycled concrete. Compared with ordinary concrete of the same strength, the rigidity becomes smaller, the brittleness decreases, and the plasticity is better.
4. Conclusion

By mixing calcined diatomite, it can effectively fill the macroscopic cracks existing in the recycled coarse aggregate itself, and play the dual role of volcanic ash effect and micro-aggregate effect with fly ash, thus improving the compressive strength of vitrified micro bubbles recycled concrete. Compared with RC-0-0, the compressive strength of RC-0-3 in 28d increased by 9%.

With the amount of vitrified micro bubbles increasing, the apparent density, compressive strength, splitting tensile strength and elastic modulus of recycled concrete all show a downward trend. When the content of vitrified micro bubbles is 100%, the cubic compressive strength of recycled concrete is 32.36MPa, which can still meet the requirements of C30 concrete strength level, while the apparent density is only 1945kg/m³, which is about 2384kg/m³ lower than ordinary concrete. 18.4%.

By collating and analyzing the test data, the linear relation expression between $f_c$ and $f_{cu}$ is put forward: $f_c = 0.81 f_{cu}$. which indicates that it is more safe to calculate the axial pressure $f_c$ of vitrified micro bubbles recycled concrete according to the provisions of JGJ12-2006 "Design Rules for Light Aggregate Concrete Structures".

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