Study on the Property and Mix Ratio of CA and L•SAC Recycled Aggregate Planted Concrete

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Abstract. This paper studies the influence of different water-cement ratio configuration of recycled aggregate planted concrete on performance, the permeable property and drying shrinkage and the influence of different gelled material against compressive strength. At last, the plant growth performance of the planted concrete is analyzed through the whole process of screening, seeding and long-potential recording of the plants. It is found that the compressive strength of CA-R (recycled aggregate aluminate cement concrete) and L•SAC-R (recycled aggregate have low alkalinity) is higher, which is 7.6 MPa and 7.4MPa, respectively. Compared with the natural aggregate, the against compressive strength of the recycled aggregate is much smaller, and the difference of the experiment blocks with different age conditions is not large; It is better to set the porosity of the planted concrete between 22% and 35%; On the one hand, the total porosity of the recycled aggregate planted concrete is always slightly higher than that of the natural aggregate planted concrete, which is basically maintained at 31.7% and slightly higher than the design value; On the other hand, the total porosity of CA-R is larger than that of L•SAC-R and P•O-R (recycled aggregate ordinary Portland cement concrete), and compared with the total porosity, the variation of connected porosity is not obvious. In addition, the water permeation coefficient of 20-40mm single-stage concrete is between 15-19mm/s; And the dry shrinkage of aluminate recycled aggregate planted concrete is larger, there are different degrees of cracks on the surface and aggregate bonding. Among the three plants selected during the experiment, Festuca arundinacea and Alfalfa had good adaptability, but Bermuda grass had low adaptability.

1. Introduction

The common concrete is made of a material such as a gelled material, water and natural aggregate. The engineering application performance of concrete is excellent, and it is one of the most construction materials that human used, but its water permeability and ecological compatibility are poor and the ecological benefit is not obvious. The planted concrete is an ecological concrete with a porous structure, and the regenerated aggregate planted concrete is prepared by using the recycled aggregate as the coarse aggregate on the basis of the planted concrete, and is a green-type ecological concrete with high ecological effect and small environmental burden. Compared with the common concrete, the recycled aggregate planted concrete has excellent water permeability, good heat insulation performance and light property, and the requirements of people for the excellent biological adaptability and the plant growth characteristics due to the concrete capable of growing plants are met.

In order to make recycled aggregate planted concrete play its ecological and economic value and
ensure that plants can grow normally and efficiently, the following problems need to be studied and solved: (1) To provide sufficient space and porosity for plant root growth [1]; (2) Ensuring that the permeability of this material meets the requirements of plant growth; (3) Finding out the adaptability of different plants to plant concrete.

In the natural coarse aggregate of nature, for example, limestone and granite are considered to be a good candidate for making porous concrete due to their low water absorption and low pressure crush index, etc. but because of resource limitations and mining limitations, the large-scale application of natural aggregate to the planted concrete is constrained [2]. In view of the contradiction of resource tension and exploitation limitation, and finding a new and sustainable development material as an alternative aggregate is the key of the technology of planted concrete. At present, the main idea for finding materials for replacing natural aggregate is to obtain from various waste products, such as metal slag and construction waste [3].

Nowadays, the construction waste has been assessed as an undeveloped resource with high value potential, and it was produced more than 650 million tons a year, of which waste concrete accounts for 85 per cent [4]. Therefore, the production of porous concrete with waste concrete as recycled aggregate will offset the high energy consumption mining process of natural aggregate and protect the environment from the influence of landfill. More importantly, it is very convenient and cost-effective to use waste concrete to handle recycled aggregate [5]. All of the above advantages make waste concrete as an energy efficient, environmentally friendly material widely used, such as bulk packing, bank protection, subgrade, drainage structure substrate, sound barrier and dike, etc. [4]. In another aspect, plants grown on the planted concrete should meet the conditions of rapid germination, high germination rate and developed root system and being native species. And due to the different climatic conditions in different regions, the design and preparation scheme of the selected planted concrete and the selected plant species are also different. The experiment area in this paper is located in Guangxi Zhuang Autonomous Region, during the experiment period, Guangxi region is warm and humid with less cold weather. Therefore, for the above reasons, the experiment selected the Festuca arundinacea which likes cold, wet and warm climate and can grow well in rich, moist and organic soil. And the experiment also selected the Alfalfa which best suitable growth temperature are 10℃~25℃ and water-resistant Bermuda grass with good salt resistance [6,7].

2. Materials and experiment methods

2.1 Materials
The P•O42.5 ordinary portland cement.
The L•SAC42.5 low-alkalinity sulfoaluminate cement.
The CA-50 aluminate cement.
Coarse aggregate with particle size of 20-40mm was used in this experiment.
Natural coarse aggregate selected limestone gravel, recycled coarse aggregate selected waste concrete in this experiment.
The planted soil used in the experiment is a kind of universal nutritive soil, which mainly composed of peat, coconut husk, bark and water retaining agent, etc.

2.2 Methods
(1) Water absorption: The water absorption of planted concrete is determined by referring to the experiment method of coarse aggregate water absorption in SL/T352-2006 Hydraulic Concrete experiment Regulations.
(2) Compressive strength: Compressive strength is the main mechanical property of planted concrete as well as the evaluation basis of durability. In this paper, the compressive strength of planted concrete was experimented by the universal hydraulic experimenting machine produced by Shanghai Xinsansi Metrological instrument Manufacturing Co., Ltd., and by referring to the SL352-2006 hydraulic concrete experiment regulations. The main method is as follows: make a
150mm×150mm×150mm plant-grown concrete cube experiment block, pressurized continuously and uniformly at the speed of 0.1-0.3Mpa/s until the specimen is destroyed. When the specimen reaches the age requirement, calculate the compressive strength by the following formula:

\[ f_{cc} = \frac{P}{A} \]  

In this formula, \( f_{cc} \) is compressive strength (MPa); \( P \) is failure load (N); \( A \) is pressure area (mm²).

3) Porosity: There is no unified specification for the determination of porosity and the following scheme is used to determine the porosity [8]: make a 150mm×150mm×150mm plant-grown concrete cube experiment block, when the specimen reaches the age requirement, the total porosity and the communication porosity are calculated according to the following equations 2 and 3.

\[ P_1 = \left(1 - \frac{W_1 - W_2}{\rho_w V}\right) \times 100\% \]  
\[ P_2 = \left(1 - \frac{W_3 - W_2}{\rho_w V}\right) \times 100\% \]  

In these formulas: \( P_1 \) and \( P_2 \) is total porosity and connected porosity; \( W_1 \) is the mass of experiment block after 24 h in air (g); \( W_2 \) is the mass of experiment block drying in air after 24 hours (g); \( W_3 \) is the mass of experiment block in water after soaking for 24 hours (g); \( \rho_w \) is the density of water (g·cm⁻³); \( V \) is the appearance volume of the experiment block (cm³).

4) Permeation coefficient: The experiment of permeability coefficient was carried out according to the relevant provisions of CCJJ/T135-2009 Technical Specification for Permeable Cement Concrete Pavement [9,10].

5) Dry shrinkage rate: The dry shrinkage experiment was carried out with reference to SL352-2006 Hydraulic Concrete experiment Code.

6) Plant: The experiment selected three kinds of plant are tall Fescue and Medicago and Cynodon dactylon. And the planted experiment was carried out by top seeding. In order to ensure survival of plants in the early stage, water should be watered 2-3 times per day during the growth period, and fresh weight method should be used to measure the water content of leaves every 5 days after germination.

3. Results and discussion

3.1 Effects of different schemes on the performance of planted concrete

The effect of water-cement ratio on the actual porosity and compressive strength of two kinds of recycled aggregate planted concrete can be understood through the experiment. The target porosity of the experimental design is 30%. And the low alkalinity sulfoaluminate cement (L•SAC) and aluminate cement (CA) were selected as cementing materials, the aggregate grain size was 20-40mm, which compact packing density was 1362kg·m⁻³. The primary water-cement ratio was 0.25, 0.27, 0.29, 0.31 and 0.33, and the experiment results are shown in figure 1.
Figure 1

3.2 Effect of different gelled materials on compressive strength of concrete
The main effect of gelled materials on recycled aggregate planted concrete is that the deterioration of gelled materials will reduce the strength of recycled aggregate planted concrete. The average compressive strength at each age of the three recycled aggregate planted concrete is shown in figure 2.

As shown in figure 3 is the micrograph of slurry surface, although the surface of the 90d age L•SAC-R slurry is relatively rough, the material structure is basically continuous with no cracks and other defects; And many cracks of different length and width appeared on the surface of CA-R hardened slurry, and the maximum crack was up to 4μm. The reason was that the metastable calcium aluminate (CAH10) and dicalcium aluminate (C2AH8) produced by hydration under normal conditions would eventually transform under certain conditions to form the stable tricalcium aluminate (C3AH6).
This course reduces the volume of hydration products, increases the pores inside the slurry, and reduces the strength of aluminate brine slurry, thereby affecting the long-term development of CA-R compressive strength [11].

3.3 Permeability performance

3.3.1. Porosity. As shown in the figure 4(a), when the target porosity is set at 30%, on the one hand, the total porosity of recycled aggregate planted concrete is always slightly higher than that of natural aggregate planted concrete, which is slightly higher than the design value and basically maintains at 31.7%. The total porosity of natural aggregate planted concrete fluctuates around 30%. On the other hand, the total porosity of CA-R is greater than that of L•SAC-R and P•O-R on the whole.

3.3.2. Connected porosity. Compared with the total porosity, the variation of connected porosity is less obvious. As shown in figure 4(b), the average connected porosity of natural aggregate planted concrete is 26.43%, and that of recycled aggregate planted concrete is 26.63%. The target design value plays a major role in the connected porosity, and the change of the variation of connected porosity of each recycled aggregate planted concrete is mainly due to the error in the course of experimental preparation. Therefore, the type of gelled material and aggregate has little effect on the connected porosity of planted concrete.

3.3.3. Water permeability coefficient. When using single-grade coarse aggregate with particle size of 10-20mm to prepare planted concrete, its water permeability coefficient is generally below 10mm/s [12,13]. However, when the coarse aggregate particle size is 20-40mm, the gap between the aggregates of the planted concrete is relatively large, making the water permeability coefficient become more larger. As shown in figure 4(c), the water permeability coefficient of 20-40mm single-grade planted concrete measured in the experiment is between 15-19mm/s.

3.3.4. Bibulous rate. As shown in figure 4 (d), the bibulous rate of natural aggregate planted concrete is generally about 2%, and that of recycled aggregate planted concrete is generally between 3.4% and 3.5%, and the recycled aggregate can improve the water absorption performance of planted concrete.
by 75%. The bibulous rate of recycled aggregate is 4.92%, while that of natural aggregate is only 0.35%. Therefore, the main reason for the high bibulous rate of recycled aggregate is that the bibulous rate of recycled aggregate is higher, water penetrates through micro-cracks and pores in the slurry and is absorbed by recycled aggregates. The recycled aggregate planted concrete with high bibulous rate has strong water absorption capacity and can effectively absorb and store water, and this works in two ways: Firstly, it can give play to the function of self-curing and maintaining the strength of concrete during the middle and later stage; Secondly, the high bibulous rate of the recycled aggregate can provide water for the root system of plants in the pores to some extent when the external water injection is low.

![Comparison total porosity](image1)

![Comparison of connected porosity](image2)

![Comparison of permeability coefficient](image3)

![Water absorption rate of planted concrete](image4)

**Figure 4**

3.4 Dry shrinkage

As the recycled aggregate, the ultimate compressive strength of the recycled aggregate planted concrete is relatively small compared with that of the common recycled aggregate concrete, and the resistance to failure is poor. But the planed concrete has a large pore structure which is communicated, and has strong flexibility in the axial direction. The large pore structure of recycled aggregate planted concrete makes its dry shrinkage regularity different from ordinary concrete. The figure 5 is dry shrinkage cracks diagram, during the whole experiment stage, the cracks on ca-r are mainly the cracks in the bond of aggregate. And the surface of the specimen was smooth and without cracks at the beginning; When the experiment age reaches 21 days, the crack of CA-R specimen appears vaguely in the place of aggregate bond, and then the crack expands gradually in the place where aggregate bond is bonded, when the experiment age reaches 40 days, the expansion of crack is basically completed. And there are no cracks appeared on the L•SAC during the whole course, it explained the strength shrinkage of ca-r in the later stage from the perspective of dry shrinkage and why the cracks had not appeared on the L•SAC.
(a) The cracks on the CA-R 1      (b) The cracks on the CA-R 2
(c) The cracks on the CA-R 3       (d) L•SAC-R Smooth surface of specimen

Figure 5 Dry shrinkage crack

The variation of dry shrinkage values of L•SAC-R, CA-R and P•O-R is shown in the figure 6. The whole dry shrinkage course of recycled aggregate planted concrete consists of two stages: rising and stabilizing. Compared with P•O-R, the increase of dry shrinkage of CA-R and L•SAC mainly focuses on the first 56d of age, and the dry shrinkage process is completed about 30d earlier. In the course of dry shrinkage, CA-R and L•SAC-R grew the fast experiment in the first 7 days, completing 40% of dry shrinkage. Then the slope gradually decreases, completing 40% in 40d, and the age reaches 60d, the dry shrinkage growth basically stops. The dry shrinkage rate of both of them is $49.97 \times 10^{-5}$ and $35.26 \times 10^{-5}$ respectively.

Figure 6 Dry shrinkage changes with age

3.5 plant growth performance

The Festuca arundinacea, Alfalfa and Bermuda grass were selected for planting in this experiment and contrast experiments were carried out in ordinary soil at the same time. The germination and growth of three kinds of plants in the soil and recycled aggregate were recorded from seeding, and the growth status and trend of plants were described by measuring the length of leaf stem, root system and leaf moisture content. The specific situation is shown in figure 7 and 8.

The Festuca arundinacea:
Comparing the growth and development of three kinds of plants after a period of planting, maintenance and observation. Due to the rapid germination and growth of Festuca arundinacea and Alfalfa, the plant height was observed every day, and the fresh weight method was used to measure the water content of leaves every 5 days after germination for 2d. During the first 25d growth period, seedlings should be watered 2-3 times a day to ensure the survival rate of plants.

As can be seen from the above pictures and the planting experiment, the Festuca arundinacea grows very rapidly and have good adaptability; Alfalfa grows relatively slowly in the longitudinal direction. After 30 days, it grows vigorously and has good adaptability; The Bermuda grass growth is extremely slow, with less than 50% germination rate, extremely difficult growth and low adaptability.

4. Conclusion
The conclusions are as follows:

(1) According to the relationship between water-cement ratio, actual porosity, net slurry strength and concrete strength, the optimal water-cement ratio range is determined to be 0.29-0.31, which can take into account the strength and permeability of recycled aggregate planted concrete.

(2) In the three kinds of recycled aggregate planted concrete (L•SAC-R, CA-R and P•O-R), the compressive strength of L•SAC-R and P•O-R has been in the process of increasing, but the strength of the latter stage of the CA-R appeared the phenomenon of shrinkage; When the age reaches 90d, L•SAC-R material structure is continuous, without the formation of defects such as cracks; Many cracks appeared on the surface of the hardened slurry of CA-R, which reduced the strength of aluminate brine slurry, thereby affecting the long-term development of the compressive strength of CA-R.

(3) In the experiment, the permeability coefficient of recycled aggregate planted concrete prepared by large particle size aggregate is up to 19mm/s, it may lead to poor water and fertilizer retention performance of planted concrete. Therefore, it is necessary the porosity and pore structure of recycled aggregate concrete. And compared with natural aggregate, recycled aggregate with higher water absorption rate can improve the water absorption performance of planted concrete by 75%.

(4) Among the 90d dry shrinkage rates of P•O-R, CA-R and L•SAC-R, the CA-R was the largest, and only CA-R surface showed obvious cracks, and it is one of the main reasons leading to the reduction of compressive strength of aluminate cement recycled aggregate.

(5) The Festuca arundinacea and Alfalfa have good adaptability and Bermuda grass growth is extremely slow with low adaptability. Relatively speaking Festuca arundinacea and Alfalfa can better adapt to the recycled aggregate planted concrete prepared in the experiment.
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