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Effect of Lime-bone Ratio on Compressive Strength and Void Fraction of Recycled Green Ecological Concrete

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ABSTRACT

In order to study the influence of ash-aggregate ratio on compressive strength and void fraction of recycled green eco-concrete, the green eco-concrete prepared with recycled aggregate is selected in this study, which conforms to the concept of sustainable development. The effective porosity, compressive strength and permeability coefficient of concrete are studied, so as to determine the impact of different lime-aggregate ratio and water-cement ratio on recycled green ecological concrete. It is found that with the increase of the ash-bone ratio, the compressive strength decreases, and the ash-bone ratio is negatively correlated with the compressive strength. With the increase of the ash-bone ratio, the effective porosity increases, and the ash-bone ratio is positively correlated with the effective porosity. The compressive strength increases with the increase of water cement ratio. The water cement ratio is positively correlated with compressive strength, and the influence of water cement ratio on effective porosity shows a complex trend of rising first and then decreasing. This study lays a foundation for choosing suitable green ecological concrete, applies green ecological concrete to practical projects, and verifies the feasibility of engineering application.

INTRODUCTION

Cement concrete is one of the most widely used man-made building materials at present. The mass production and use of concrete provides convenient living facilities for human beings, promotes the rapid development of economy, and inevitably causes serious impact on the earth's environment and ecological balance (Akyıldız et al. 2017). The non-permeability and low permeability of traditional concrete affects the growth of surface plants, reduce the area of urban greening, and cause the imbalance of urban ecosystem (Ujin et al. 2017). In the production and use of traditional cement concrete, a large amount of limestone is decomposed, and a large number of other harmful gases, such as CO_2 with greenhouse effect, will emit a large number of harmful substances. A large number of large particles of dust will be also produced, and the environment will be seriously damaged (Li et al. 2017). Concrete is hard in texture and rough in surface, which results in poor tactile effect. At the same time, the colour of concrete is monotonous and grey, so the living space constructed by concrete materials is easy to give people a feeling of coarseness, hardness, cold, dark and lack of vitality.

In order to meet the needs of economic development, to preserve the natural environment and resources on which human beings depend for survival, to make future generations develop sustainably, and to achieve the goal of sustainable development, the damage caused by concrete to the environment must be controlled within the minimum limit. To ensure that each process has the least impact on the environment, the whole process control of concrete materials from research, production and application should be carried out. Therefore, breaking through the category of traditional building materials, developing new environmentally friendly concrete and ensuring its harmonious development with the environment has become one of the directions of concrete research and development (Ofuyatan & Edeki 2018). According to the use function of eco-friendly concrete, it can be divided into three categories: vegetation greening concrete, marine biological protection concrete and permeable concrete (Deng et al. 2018, Wang & Wang 2017).

The so-called vegetation greening concrete refers to the concrete and its products which can adapt to plant growth and can be planted on it. This concrete has the function of protecting the environment and improving the ecological conditions, while basically maintaining its function as a structural material (Chao et al. 2018). The green ecological concrete described in this research is a kind of vegetation greening concrete. This kind of green ecological concrete is a porous skeleton structure, which guarantees the existence of a certain amount of connected pore. The pore can store water and nutrients needed for plant root growth, so as to ensure the normal growth of grass on the surface of concrete. At the same time, since this kind of coagulation has more pores and better permeability, it can improve the moisture and heat exchange capacity of concrete surface, reduce the surface temperature of concrete material and improve the groundwater level. The application of green ecological concrete in road slope protection or parking lot can play a protective role, as well as play a role in greening the environment and soil and water conservation. It has good application prospects.

MATERIALS AND METHODS

Testing method of effective porosity: Porosity is an important parameter of permeable concrete. It reflects the structure of permeable concrete. The size of porosity represents the quality of permeability. There are three kinds of pore in permeable concrete: closed pore, semi-connected pore and connected pore. These three kinds of pore are collectively called full pore. Among them, closed pore refers to independently closed pore. Semi-connected pore refers to one end closed; the other end connected with connected pore. Connected pore refers to open pore at both ends. Permeability is measured by effective porosity. Target porosity and effective porosity are intrinsically related but different. For green eco-concrete, only the interconnected and semi-connected pore can ensure its water permeability function, thus ensuring the normal growth of plant roots. If free water can be discharged from the pore, it can be considered as effective pore. Therefore, the interconnected pore belongs to the effective pore. The water in the semi-connected pore is stagnant, but it can be discharged after simple treatment, and the semi-connected pore has sound absorption, so the semi-connected pore can also be called effective pore. The closed pore has no effect on the permeability, nor does it help the sound absorption effect of the permeable concrete. However, its proportion in the whole pore is very small, so it can be neglected.

Preparation of specimens: The test method is carried out in accordance with the ordinary concrete test rules. The specimens are made according to a certain water-binder ratio and bone gelatinization. Three cubic specimens of 100mm * 100mm * 50mm are made in each group. The specimens are demolished 24 hours after moulding and maintained in the standard curing room until 28 days of age. The test pieces are put into the PVC test mould, and the inner diameter of the test mould is the same as the size of the test piece. The test die must be open to the top without leakage. Weight G1 of the inner sleeve specimen is weighed. The test model with the test piece is put into the glass cylinder with water camp. The height of the water pipe from the bottom of the cylinder is slightly lower than that of the test piece and the test model. Water is carefully injected into the glass cylinder, and it should be noted that water should not be injected into the test model. The height of the injected water is slightly higher than that of the specimen, and the part of the water to be raised will flow out through the water pipe. The height of the injected water will be stabilized and a test tube which can be accurately read will be placed under the water pipe after the specimen. Water is slowly injected into the test mould. When the injected water is level with the surface of the test mould, the injection should be stopped, and it is necessary to stand still for about 5 minutes until the surface of water is stable. The volume of green eco-concrete is M_1. According to formula 1, the effective porosity of green eco-concrete can be calculated.

$$A = 1 - [(M_2 - M_1)/(\rho_W \times V)] \times 100\% \qquad \ldots(1)$$

Where, A is the effective void fraction of GEC (concrete), M_2 is the weight of the sample in air after being dried and placed at (20 ± 2)°C and (60 ± 5)% relative humidity for 24 hours. M_1 is the weight in water after being immersed in water and saturated by water absorption. r_W is the density of water. V is the apparent volume of GEC measured and calculated by callipers.

Test method for permeability coefficient of specimens: At present, there is no standard method to determine the permeability of GEC in China. Generally, the determination of permeability coefficient can be divided into fixed-head method and variable-head method according to different test principles. According to Japanese research experience, fixed-head method is generally suitable for measuring the permeability coefficient of materials with good permeability, while variable-head method is generally suitable for measuring the permeability of materials with poor permeability. Therefore, the constant head method is adopted in this experiment. During the test, the concrete specimens cured up to the age are placed in the permeable cylinder, and certain cementing materials are used to ensure that the specimen and the wall of the permeable cylinder are impermeable. Then water is injected from the upper part of the pervious cylinder sleeve. Water enters the positioning bucket through concrete and is discharged from the outlet pipe. When water is injected, excess water overflows from the overflow pipe. When the amount of water injected is balanced with the amount of water discharged from the outlet pipe and the amount of water overflowing from the outlet pipe, the stopwatch is activated. The quantity Q of water discharged from the outlet pipe is measured at the same time, and the water temperature at that time can be measured to calculate the permeability coefficient of concrete through formula 2. The permeability coefficient of GEC is determined as follows. Under a certain water head, the amount of water passing through concrete in a unit time is proportional to the permeable area of concrete and is inversely proportional to the permeable thickness of concrete.

$$K_T = (Q \times D) / [A \times H \times (t_2 - t_1)] \qquad \ldots(2)$$

Where, K_T is permeability coefficient (cm/s) at water temperature T°C, Q is water amount (cm^3) through concrete from time T_1 to T_2, D is the thickness (cm) of GEC specimens, A is the area (cm^2) of GEC specimens, H is the water head (cm) and (t_2 - t_1) is determination time (s).

In this experiment, the sealing problem between concrete and sleeve has been puzzling people. Because of various errors in the test, the size of each specimen cannot be exactly the same. There will be a gap between the specimen and sleeve. Water will pass through this gap during the test, and Q is the amount of water passing through the surface of the specimen in a certain time. Therefore, the gap will increase Q and make the result bigger, which cannot reflect the real situation. For the problem of edge leakage, researchers have used a variety of methods to bridge the gap. Some researchers use liquid wax or cement slurry to seal around the specimen, while others use rubber or oil slurry to seal the specimen and sleeve edge. In this test, cement slurry is used to seal the surrounding of the specimen. The consistency of the cement slurry should be appropriate. Excessive thinning will infiltrate into the specimen, plug the pore and affect the permeability. Excessive thickening will not be easy to smear. During the test, the specimen is evenly smeared on all sides, and only two permeable surfaces are left. When smearing, it should be noted that there are no gaps in the edges and corners. After about 12h, the cement slurry has been hardened, and then the sleeves and the test pieces are tightly tied together with a rope. The water permeation instrument used in the experiment is made according to the permeation principle. The specimen sleeve is made of plastic foam board with a certain hardness, so that it can ensure that there is no deformation and elasticity, and the outer casing is replaced by a bucket. Since the sleeve is made of rigid plastic foam board, it has a certain elasticity and is tightly tied with the rope, so that the sealing between the specimen and sleeve can be very good.

Test method for compressive strength: Compressive strength refers to "Standard for Testing Method of Mechanical Properties of Ordinary Concrete". Cubic specimens with side length of 150mm * 150mm * 150mm are adopted. Six specimens are taken as a group, and the arithmetic average value of the measured values of six specimens is taken as the compressive strength value of the group of specimens.

Determination of grey bone ratio (G/C): The size of the cement-aggregate ratio (G/C) determines the thickness and void age of the mortar layer wrapped on the surface of aggregate particles. When the aggregate dosage is fixed, increasing the ash-bone ratio (G/C) will reduce the amount of cement used. The cement slurry wrapped on the aggregate surface will be too thin. Although the porosity of the permeable eco-concrete will be increased, its strength will be decreased. On the contrary, if the ratio of cement to bone (G/C) is reduced, the corresponding amount of cement will increase, and the cement slurry wrapped will become thicker. The strength of permeable eco-concrete will be improved, but the porosity will be reduced, which will affect the permeability of permeable eco-concrete. Therefore, it is also an important factor affecting the strength and permeability of concrete. Since the strength of recycled aggregate itself is much lower than that of natural aggregate, a smaller ash-aggregate ratio is chosen. In this experiment, three levels of ash-aggregate ratio are adopted, namely, 3.5, 4.0 and 4.5.

Determination of W/C: Whatever the type of concrete is, W/C is an important index. The water cement ratio of recycled permeable concrete affects not only its strength but also its permeability. When W/C ratio is small, the mixture is dry and astringent, and its workability is poor. Moreover, because some cement cannot be fully hydrated, it will exist in the pore in the form of powder, which makes aggregates not well cemented together, and is not conducive to the improvement of strength. If the water cement ratio (W/C) is too large, the cement slurry will be too thin, which will block up the pore of concrete, affect the permeability of permeable ecological concrete. The compressive strength will be reduced. After a lot of literature research and trial matching, the water cement ratio of 0.3, 0.35 and 0.4 level are adopted in this experiment.

RESULTS AND DISCUSSION

The law of single factor affecting the performance of green eco-concrete: The results of the influence of water cement ratio and ash-bone ratio on green eco-concrete are shown in Table 1. The change trend is shown in Fig. 1.

Effect of compressive strength: When other factors remain unchanged, the water cement ratio (W/C) is positively correlated with strength, and the strength increases with the increase of W/C. When other factors remain unchanged, the compressive strength is negatively correlated with the bone-cement ratio (G/C). That is to say, with the increase of the bone-cement ratio (G/C), the compressive strength tends to decrease. This is because when the cement-aggregate ratio (G/C) is small, the mortar is relatively more, and the mortar layer can fully wrap the aggregate, so the cohesive force between aggregates is stronger. At this time, the failure generally occurs on the side of the matrix, and the overall

Table 1: Effect of single factor on green eco-concrete performance.

Influence factor		Compressive strength /MPa		Effective porosity /%	Permeability coefficient mm/s
		7d	28d		
Water cement ratio (W/C)	0.3	1.7	2.9	38.5	6.13
	0.35	2.1	2.5	40.8	10.17
	0.4	4.1	4.6	35.2	6.65
Cement bone ratio (G/C)	3.0	5.2	6.1	32.7	4.92
	3.5	3.9	4.4	35.1	6.68
	4.0	1.8	1.9	39.9	10.96

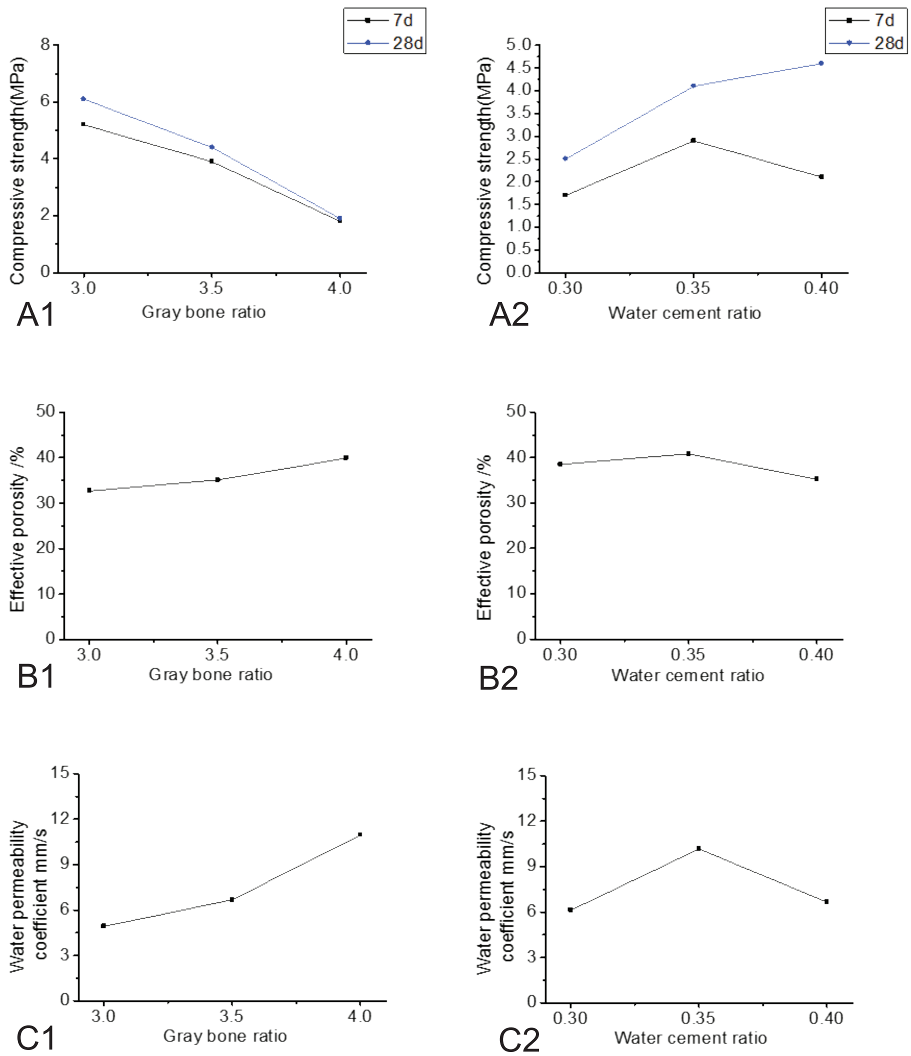

Fig. 1: Effect of water-cement ratio and ash-bone ratio on green eco-concrete (A1: Effects of different grey-bone ratio on compressive strength; A2: Effects of different water-cement ratio on compressive strength; B1: Effects of different grey-bone ratio on effective porosity; B2: Effects of different water-ash ratio on effective porosity; C1: Effects of different lime-bone ratio on permeability coefficient; C2: Effect of water-cement ratio on permeability coefficient).

strength of the specimen is higher. When the cement-cement ratio (G/C) increases gradually to a higher level, the bond strength between aggregates is not good because the cement slurry is not enough to wrap the recycled aggregates. The failure often occurs on the interface between aggregates, which leads to the destruction of concrete.

Effect on effective porosity: When other factors remain unchanged, the water-cement ratio shows a complex trend of rising first and then decreasing. This is because recycled aggregate absorbs part of the water. When the water cement ratio is small, the remaining water is not enough for cement hydration reaction, and unhydrated cement will be filled in the pore of permeable concrete in the form of powder, which will block the pore between aggregates, and make it unable to form up and down connected permeable channels. Therefore, the effective porosity is small. When the water cement ratio reaches 0.35, from the mixing situation, the mixing is uniform, the drying and wetting is moderate, and the aggregate surface is coated with a layer of thin and uniform cement slurry, which forms a connecting void between aggregate and aggregate. At this time, the effective void rate reaches the maximum, and the effective void rate is 40.3%. When the water cement ratio continues to increase to 0.4, the cement slurry layer on the aggregate surface becomes thicker, the specimen becomes compact and the porosity decreases. Therefore, the water permeability decreases gradually. With the increase of cement-aggregate ratio, the surface area of aggregate increases, and the cement slurry used to wrap the aggregate surface is relatively small, which is not enough to form a uniform cement slurry layer on the aggregate surface, so the effective porosity will increase continuously.

CONCLUSION

From the point of view of environmental protection, green and sustainable development, the effective porosity, permeability coefficient and compressive strength of recycled green eco-concrete specimens are studied, and the effects of water-cement ratio and lime-bone ratio on the effective porosity, permeability coefficient and compressive strength of concrete specimens are studied with water-cement ratio and lime-bone ratio as variables respectively. It is found that the water cement ratio (W/C) is positively correlated with the strength, and the strength increases with the increase of W/C. Grey-bone ratio (G/C) is negatively correlated with compressive strength, that is, with the increase of grey-bone ratio (G/C), compressive strength tends to decrease. With the increase of ash-bone ratio, the effective porosity will increase continuously. When the water cement ratio is equal to 0.35, the maximum effective porosity can reach 40.8%. At this time, the permeability is the best, and the permeability coefficient reaches the maximum value of 10.17mm/s.

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