Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (12): 2311-2315, 2013
ISSN 1812-5654/DOI: 10.3923/jas.2013.2311-2315

Laboratory Investigations on Mechanical Behavior of Ecology Porous Concrete under Uniaxial Compressive Loading

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Abstract: Compared with Traditional Concrete (TC), Ecology Porous Concrete (EPC), has a small amount of sand which is porous and good permeable with a certain strength, thus it is widely applied to civil engineering, roads and environmental engineering. Therefore, it is very important to study the basic mechanics nature of EPC. This study has designed 1, 7 and 14 day three different curing times to study uniaxial compressive test of EPC and TC. The tested results show that: (a) Compared with TC, the failure process of EPC tends to be more brittle, (b) The compressive strength of TC increases significantly with the growth of curing time, while the compressive strength of EPC has no significant change with curing time, (c) TC and EPC basically have the same strength reserve coefficient K_s and deformation reserve coefficient K_d with the curing time of 1 day, (d) For TC, K_s increases with the growth of curing time, while K_d decreases with it; but K_s and K_d of EPC are not sensitive to curing time. The above research results are available to related engineering design.

Key words: Ecology porous concrete, mechanical behavior, compressive strength, security reserve

INTRODUCTION

With the rapid development of socio-economy, in order to achieve high strength and durability, Traditional Concrete (TC) is always in pursuit of compactness of its structure, which has brought many negative effects. Currently, more than 80% area of the urban surface is covered by concrete buildings and concrete roads, but this kind of compacting concrete is lack of air permeability and water permeability and is poor to adjust the temperature and humidity of the air, thus produces a more severe heat island effect (Zhang *et al*., 2009; Xing *et al*., 2011). Rainwater can't seep into underground for a long time, so that the city water level is declining, which would affect the ground flora's growth, resulting in the urban eco-system disorders. These attract both the domestic and foreign research scholar's full attention. To this end, the development of a type of Ecology Porous Concrete (EPC) that is breathable, permeable, and arable and have enough strength to replace the compacting concrete to reduce the urban heat island effect, and improve the ecological balance is very important.

Lot's of effort has been devoted to this study from different aspects by researches all over the world. In order to explore mix design method of porous ecological concrete, Xie *et al*. (2008) analyzed the strength and porosity of porous ecological concrete based on orthogonal test method. Xing *et al*. (2011) investigated the controlling indicators of plant-growing of ecological concrete by comparing the internal structure and composition of normal concrete.

The effects of mix proportions on the properties of porous ecological concrete and its coexistence with plants were discussed by Quan (2011). Experimental study on eco-environmental effect of porous concrete was carried out and minimum compressive strength and valid porosity content were studied by Gao *et al*. (2008) and Xiong *et al*. (2009), too.

This study conducted the uniaxial compressive test of EPC and TC, studied the EPC's failure mode, crack stress and crack strain, compressive strength and failure strain, and elaborated the development law of their respective development with curing time. We further discussed the strength reserve and deformation reserve capacity of EPC after cracking by strength reserve coefficient and deformation reserve coefficient. The comparison between EPC and traditional concrete showed the good feasibility of the EPC engineering application.

TEST PREPARATION

The coarse aggregate used in this test is stone with a particle size of 20-30 mm. The fine aggregate is ordinary river sand with medium particle size. The cement is the

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Table 1: Test material amount of EPC and TC/(kg m^{-3})

Category	Cement	Sand	Stone	Water
EPC	270.0	110.9	1057.1	120
TC	270.0	443.6	724.4	120

composite Portland cement P.C32.5. The mixing water is ordinary tap water. The instruments are SJD60 forced concrete mixer and SYE-600 press machine of the Civil Engineering Professional Laboratory in Shaoxing University. According to the chosen aggregate size, the water/cement ratio used by the specimens is 0.45. The specimens are divided into two groups: EPC and TC and each group has 3 different curing times, 1, 7 and 14 day.

At each curing time, use three cube specimens with 150 mm side length to conduct uniaxial compressive test. The mixing of EPC and TC specimens is shown in Table 1. Both prepare and curing processes of the recycled concrete specimens are done in Civil Engineering Professional Laboratory of Shaoxing University. After molding of the specimens, cover the surface to prevent water evaporation and then remove the cast after 24 h. The curing conditions of the specimens are the same that is putting on the thermostat conservation tank with water until to the experimental set age.

The SYE-600 press machine is used to load uniaxial compressive stress, and it is vertical compression and horizontal expansion. During the test, the average stress and average strain of the specimens are simultaneous recorded and the failure characteristics are appropriate recorded, too.

FAILURE CHARACTERISTICS

During the initial stage of the test, TC specimen does not appear obvious cracks. When the load reaches the one bigger loading, the specimen appears the first visible crack. This crack is short and thin, as shown in Fig. 1. When the load further increases, the crack extends from the middle to both sides to form a diagonal crack, then rapid forms a large crack throughout the whole surface, resulting in the destruction of the entire specimen. When eventually destroys, the specimen forms two vertical pyramid type failure surfaces, as shown in Fig. 2.

The experimental results show that the destruction of the EPC mostly occurs in the contact point between the coarse aggregates. Because the porosity of the EPC specimen is very large, that exhibits the characteristics of a typical brittle fracture. In the initial stage, it is difficult to find the small cracks; once the crack appear, it will rapidly run through the entire surface of the specimen until the specimen is completely destroyed, as shown in Fig. 3. Since, the small amount of sand in the EPC specimen causes larger porosity, there are most contact points between the coarse aggregate stones, so, that its final destruction section is not very regular but a collapsing type, as shown in Fig. 4.

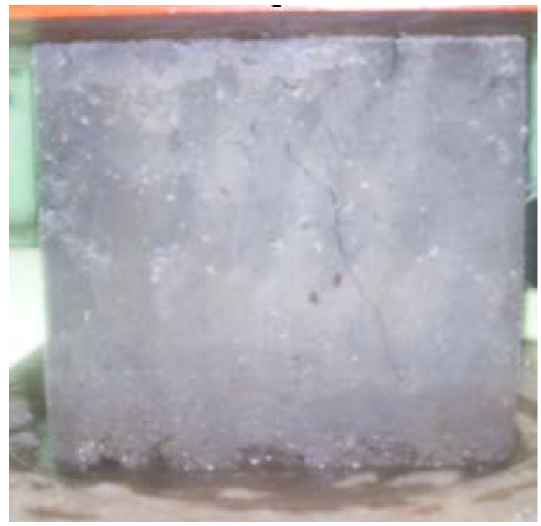

Fig. 1: Initial visible crack of TC specimen

Fig. 2: Vertical pyramid type failure of TC specimen

The most obvious differences between the TC specimen failure characteristics and the EPC specimen failure characteristics:

- The TC specimen has a longer time development process of cracks while the EPC specimen is rapidly destroyed after the initial cracking

Fig. 3: Cracks of the EPC specimen

Fig. 4: Failure pattern of the EPC specimen

- The TC specimen failure is a two vertical pyramid type while the EPC is an irregular failure type of the collapse

TIME EFFECT OF COMPRESSIVE STRENGTH

According to the experimental data, the corresponding compressive strength of the EPC specimen and the TC specimen with different curing times is calculated, as shown in Table 2.

Seen from Table 2, the TC specimen strength is gradually increasing with the growth of the curing time, and at 14 day the strength reaches more than 200% of the 1 day strength. On the contrary, the EPC specimen strength is increasing slowly with the growth of the curing time without obvious change.

Table 2: Compressive strength of the EPC specimen and the TC specimen with different curing times/Mpa

Curing time	1 day	7 days	14 days
TC	8.5	15.3	18.0
EPC	4.1	4.2	4.8

The test used the ordinary portland cement, medium sand, water and stones as the material without adding other admixtures. However, the development mechanism of the EPC specimen is different from traditional concrete. After the EPC mixture mixing, only a part of the water supplies for concrete hydrating, and the sand content is much less than traditional concrete, so most of the water evaporates by the form of vapor. After aggregation structure is gradually formed, resulting in the EPC mixture fluidity becomes low and dry with the development of time, which forms the large holes in the concrete internal. From the microscopic point of the chemical reaction to analysis this phenomenon, the hydration, condensation and hardening of cement are the main reasons of concrete condensation and strengthen. Hydration of the cement particles starts from the surface, the reaction between the cement particles and water will happen when contacting with each other, the corresponding hydrate is formed and dissolved in water. Since, the solubility of hydrate is very small, and the generation rates is higher than its rate of diffusion into the solution, after a few minutes the solution around the cement particles becomes a supersaturated solution of the hydrate, simultaneous deposits substances such as C-H crystal inclusions on the surface of the cement particles. With the elapse of time, the neonatal hydrates increase, the film layer of the cement particles surface get thicken, the void between the particles is gradually reduced, and condensed into the porous space lattice. With the increase of the curing time, the above process is ongoing; the solid hydrates gradually increase and diffuse into the pores, that make the crystal lattice structure to strengthen and be denser, the corresponding strength to increase. But the sand content of EPC is very small, thus, resulting in a point-to-point contact between the coarse aggregate stones, the contact area between the aggregate reduces, the porosity becomes large, the solid hydrates produced by the hydration of cement is not enough to make the concrete specimen denser, so the strength of EPC does not increase with the increase of curing time but always in a relatively stable state.

SECURITY RESERVE AFTER CRACKING

Security reserve is the ability to continue working after specimen's cracking. It has two kinds: The strength reserve and deformation reserve. Strength reserve reflects its ability to continue bearing external forces after cracking by the analysis of the ratio between crack stress and compressive strength. Deformation reserve reflects its ability to continue resisting deformation after cracking by the analysis of the ratio between crack strain and failure strain.

Strength Reserve: Crack stress refers to the corresponding average stress value when the first crack appears during compression test of the concrete specimen, denoted by f_{cr}, while compressive strength means the average stress value when the specimen is completely destroyed, denoted by f_u. Thus, the strength reserve coefficient K_s is:

$$K_s = (1\text{-}f_{cr}/f_u)\times 100\% \qquad (1)$$

As shown in Eq. 1, the theoretical value of K_s is in the range of 0-1. The smaller K_s is, the closer f_{cr} to f_u, the smaller the strength reserve is after cracking, and vice versa.

There are three specimens in the concrete tests at curing time of each group, therefore, we use the average value of the three specimens to represent the strength coefficient K_s of this curing time for the entire groups, as shown in Eq. 2:

$$K_s = \frac{k_{s1}+k_{s2}+k_{s3}}{3}\times 100\% \qquad (2)$$

In the Eq. 2, k_{s1}, k_{s2} and k_{s3}, respectively represents three specimens strength reserve coefficient in the same group, which can be calculated from Eq. 1. Based on the test results, the K_s of TC specimen and EPC specimen after cracking are shown in Table 3 and 4.

As we can see from Table 3 and 4:

- We can believe that there is no big difference between the strength reserve coefficients of the two kinds of specimens at the curing time of 1 day
- As for the TC specimen, the strength reserve coefficient is 11% at 1day after cracking; but increases significantly with the increase of the curing time
- Strength reserve coefficient for the EPC specimen almost does not change with the change of curing time after cracking, basically stable around 12%. That is, once the EPC specimen cracks, it will be quickly and completely destroyed

Deformation reserve: Crack strain refers to the average strain value when the first crack appears during compression test of the concrete specimen, denoted by ε_{cr}, while failure strain means the average strain value when the specimen is completely destroyed, denoted by ε_u.

Defined deformation reserve coefficient after cracking K_d as:

$$K_d = (1\text{-}\varepsilon_{cr}/\varepsilon_u)\times 100\% \qquad (3)$$

By Eq. 3, the theoretical value of K_d is also in the range of 0-1. That is, the closer ε_{cr}-ε_u, the smaller K_d is, the smaller the deformation reserve is after cracking, and vice versa.

Similar to K_s, the average value of the three specimen's deformation reserve coefficient is designed to represent K_d of the group, as shown in Eq. 4:

$$K_d = \frac{k_{d1}+k_{d2}+k_{d3}}{3}\times 100\% \qquad (4)$$

In the Eq. 4, k_{d1}, k_{d2} and k_{d3}, respectively represents three specimen's deformation reserve coefficient in the same group, that can be calculated from Eq. 3.

Based on the test results, the K_d of TC specimen and EPC specimen after cracking are shown in Table 5 and 6.

As we can see from Table 5 and 6:

- We can believe that there is no difference between the deformation reserve coefficients of the two kinds of specimens at the curing time of 1 day

Table 3: K_s of TC specimen/(%)

Curing time	1 day	7 days	14 days
k_{s1}	12	15	65
k_{s2}	11	25	57
k_{s3}	10	20	69
K_s	11	20	60

Table 4: K_s of EPC specimen/(%)

Curing time	1 day	7 days	14 days
k_{s1}	13	10	14
k_{s2}	12	14	13
k_{s3}	13	8	8
K_s	13	11	12

Table 5: K_d of TC specimen/(%)

Curing time	1 day	7 days	14 days
K_{d1}	33	27	24
K_{d2}	42	29	22
K_{d3}	28	23	21
K_d	34	26	22

Table 6: K_d of EPC specimen/(%)

Curing time	1 day	7 days	14 days
K_{d1}	41	41	39
K_{d2}	40	41	38
K_{d3}	26	24	25
K_d	36	35	34

- As for the TC specimen, the deformation reserve coefficient gradually decreases from 34% at 1 day to 22% at 14 day after cracking. We can get that its deformation reserve coefficient is obviously decreased with the increase of the curing time, which is worthy for engineer's attention
- K_d of the EPC specimen gradually decreases from 36% at 1 day to 34% at 14 day with the increase of the curing time, which can almost be ignored. This shows that the deformation reserve coefficient is not significantly decreased with the increase of the curing time that is favorable to the safety for engineering

CONCLUSION

Through comparative analysis between EPC and TC specimen's uniaxial compression test, we can draw some meaningful conclusions and the major elements are as following:

- The TC specimen has a longer time crack development process, while the EPC specimen will be rapidly destroyed after the initial cracking. The TC specimen's destruction is two vertical pyramids destruction, while EPC's is the type of the collapse irregular destruction
- The strength of the TC specimen is significantly increased with the increase of the curing time, while EPC's compressive strength is almost unchanged with the increasing curing time
- There is no big difference between the strength reserve coefficients of the two kinds of specimens in the age of 1 day. However, the strength reserve coefficient of TC specimen is significantly increased with the increasing age, while EPC specimen is not sensitive to the age
- The deformation reserve coefficient of two specimens at 1 day age of cracking is basically the same to each other. However, that of TC specimen is significantly decreased with the increasing curing time, while that of EPC increases with the growth of the curing time can be ignored

ACKNOWLEDGMENT

This research was partly supported by Science Technology Department of Zhejiang Province (NO. 2012C23063, NO. 2012C21009), Ministry of Housing and Urban-Rural Development of China (NO. 2012-k3-4), and Science Technology Bureau of Shaoxing City (NO. 2012B70022), China. B. L. Wang, Z. Pan, L. L. Zhang, Z. W. Zhang, L. S. Ma and X. C. Chi took part in experiment test of this study.

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