Experimental Study on High Damping Polymer Concrete

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Abstract

The damping performance of concrete can be improved when mixed with polymer. In this paper, the standard test methods were used to compare mechanical properties and durability between polymer concrete and ordinary concrete. Vibration tests and fatigue experiments were carried out with two prestressed simple beams respectively made by polymer concrete and ordinary concrete. The loss factors of ordinary cement mortar and polymer cement mortar were measured by using dynamic viscoelastometer, and they were also analyzed by scanning electron microscope. The experimental results show that the flexural strength, splitting tensile strength and durability of the polymer concrete are higher than those of ordinary concrete. The elastic modulus and compressive strength of the former decrease slightly but yet meet the requirement of code. The loss factor of polymer cement mortar is higher than that of the ordinary cement mortar, due to the reticular formation of the polymer. The damping ratio of the polymer concrete beam is significantly greater than that of ordinary concrete beam, and their fatigue performance are similar.

Key words: polymer concrete, high damping, mechanical properties, durability, fatigue performance

Introduction

At present, high-speed railway is playing an increasingly important role in the fast-growing Chinese economy. The technology involved, however, has been proven to be challenging. Trains travelling in high-speed cause more bridge vibration than those in normal speed. Consequently, enhancing structural resistance to vibration has become the focus of recent studies. Since 1990s, researchers around the globe have been dedicating themselves to improve the property of concrete by means of adding macromolecular material, for instance: a series of studies have been conducted by Prof. Chung and his team to improve the damping property and stiffness of cement paste (Fu and Chung,1996; Li and Chung, 1998; Wen and Chung, 2000). Reference (Amick and Monteiro, 2005) reviewed the application of polymer concrete for vibration mitigation in mechanical and optical engineering. Reference (Cao et al, 2011) provided a means of increasing the damping ratio of concrete by adding carboxylic styrene butadiene latex (CSBL). Reference (Liu and Ou, 2003a; Liu and Ou,2003b; Liu and Zhou,2008) improved the loss factor of cement mortar and analyzed its microscopic mechanism by using scanning electron microscopy (SEM). Reference (Yao et al, 2005) pointed out that the mechanical performance and wearing resistance of concrete modified by CSBL are much better. Wan (2005) succeeded in improving the crush resistance of concrete by adding CSBL.

On the basis of previous work (Cao et al, 2011), the authors prepared polymer concrete in line with both construction and mechanical requirement by using materials of different origin, and conducted analysis that follow: comparison of damping and fatigue properties between normal and polymer concrete; durability tests, such as the property of polymer concrete to resist permeability, carbonization, shrinkage and early cracking; micro-structure analysis by using SEM.

Raw material and mix ratio adopted in the experiment

Ordinary Portland cement manufactured by YA DONG CEMENT CORPORATION LIMITED; Water consumption of standard consistency: 25.6%;28d compressive strength: 43.2 MPa;Coal ash: manufactured by YONG SHUN in Jiangyou, (water requirement ratio: 88%);Gravel: machine-made coarse gravel (maximum diameter: 30mm), continuous grading;Water reducing agent: catalytic high efficiency water reducing agent；Polymer emulsion: CSBL (SD622S) manufactured by BASF in Gaoqiao, Shanghai (solid content: 47%; film-forming temperature: 11℃)；Cement mix ratio is in line with the standard of C60: 1:2.52:2.82:0.36. Workability is shown in Table 1. Cement-mortar proportion is shown in Table 2. SD00: cement without any polymer;SD15: cement with 15% polymer; SJ00: cement mortar without any polymer;SJ15: cement mortar with 15% polymer;

Table 1 Workability of the specimen

Indicators of workability	Slump（mm）	Expansion（mm）
SD00	195	600
SD15	240	590

Table 2 Cement-mortar proportion

NO.	Water-cement ration	Polymer-cement ration	Fluidity
SJ00	0.42	0	243
SJ15	0.32	15	242

Mechanical property experiments

Mechanical properties including cube strength (**CS**), static compressive strength elasticity modulus (**SC**), bending strength (**BS**) and splitting tensile strength (**SS**) were tested in accordance with the standards regulated in reference (National Standard of the People's Republic of China, 2002). Trial cube sizes for each test are as follow: CS: 150mm×150mm×150mm ； SC: 150mm×150mm×300mm；BS: 100mm×100mm×400mm；SS: 150mm×150mm×150mm.Results are shown in Table 3:

Table 3 Mechanical properties

NO.	CS（MPa）	SC (GPa)	BS（MPa）	SS（MPa）
S00	68.4	38.49	6.13	4.51
S15	61.5	37.01	7.2	4.65

As indicated in Table 3, the presence of polymer results in a slight decrease in both cube strength and elasticity modulus, which still meets the requirement of C60 concrete. Table 3 also indicates an improvement in bending and splitting tensile strength.

Durability experiments

Durability properties including permeability, chloride ion permeation, carbonization, shrinkage and early cracking were tested in accordance with the standards regulated in reference (National Standard of the People's Republic of China, 2009).

Water permeability resistance test

The test was conducted by using concrete permeability automatic recording instrument and graduated compression method. Specimens were prepared in the shape of truncated cone (top diameter: 175mm; bottom diameter: 185mm; height: 150mm). At the end of compression process, neither SD00 nor SD15 shows any signs of leakage.

Fig 1 Concrete permeability automatic recording instrument

Chloride ion permeation resistance test

The test was conducted by using RCM method and chlorine ion diffusion coefficient meter (see Fig 2). Specimens were prepared in cylinder shape (height: 50mm; diameter: 100mm). Test results after maintenance 28d in standard conditions are shown in Table 4.

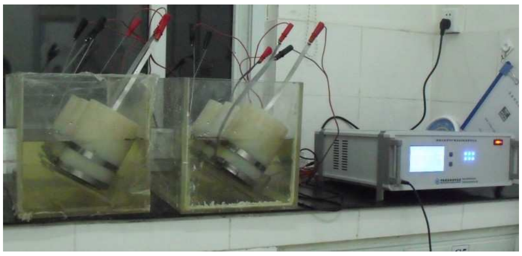


Fig 2 Test device

Table 4 Chloride ion diffusion coefficient

NO.	SD00	SD15
D_{RCM} （$\times 10^{-12}$ m^2/s）	4.2316	2.3707

Carbonization test

The test was conducted by using carbonization chamber (CO_2 concentration: 20±3％; humidity: 70±5％; temperature: 20±5℃). Test results are shown in Table 5.

Table 5 Carbonization depth (mm)

NO.	3d	7d	14d	28d
SD00	2.2	3	3.7	6.8
SD15	0	0	0	0

Early cracking resistance test

This test was designed to find out the property of concrete to resist early cracking under restrains. Test mold is made 800mm×600mm×100mm with all four sides welded with channel steels and fixed on a bottom slab with bolts. 7 stress-triggered risers made of angle bars (50mm×50mm, 40mm×40mm) and steel slabs (5mm×50mm) are fixed on the bottom slab and parallel with the short side of mold.
According to observation, reference concrete shows two visible penetrating cracks and a number of minute cracks on the surface. Polymer concrete shows two visible penetrating cracks and two smaller crack on the surface. Test results are shown in Table 6.

Table 6 Plate anti-cracking test results

NO.	Average cracking area （mm^2/crack）	Number of cracks on unit area （crack/m^2）	Total cracking area on unit area （mm^2/m^2）
S00	10.2	12.5	127.5
S15	9.4	8.3	77.9

Shrinkage test

Shrinkage tests include contact and non-contact approaches. The latter is mainly adopted for free shrinkage of early age concrete, whereas the former is for long term shrinkage. Non-contact test was done by using concrete shrinkage measuring instrument developed by China Academy of Building Research, which is capable of yielding accurate value of early shrinkage. Contact test was done by using horizontal concrete shrinkage device with an accuracy of 0.001mm. The trial cubes were prepared in 100mm×100mm×515mm. Test environment: constant temperature (room temperature: 20±2℃) and humidity (relative humidity: 60±5%);

Fig 3 Non-contact concrete shrinkage test

Fig 4 Contact concrete shrinkage test

Early shrinkage test collected data of 120 hours. Shrinkage rates are shown in Fig 5. Polymer concrete shows higher rate of early shrinkage but kept within 225×10^{-6} at the scale of 120 hours. Shrinkage rate at age 1d, 3d, 7d, 14d, 28d, 45d, 60d till 330d. Results are shown in Fig 6.

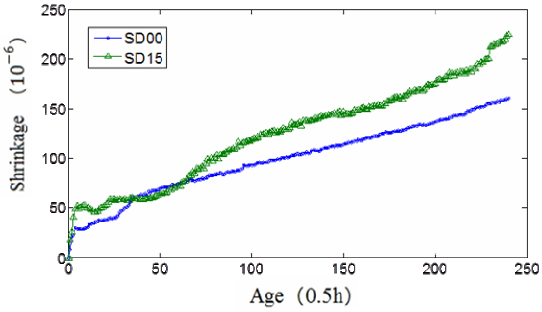


Fig 5 Early shrinkage

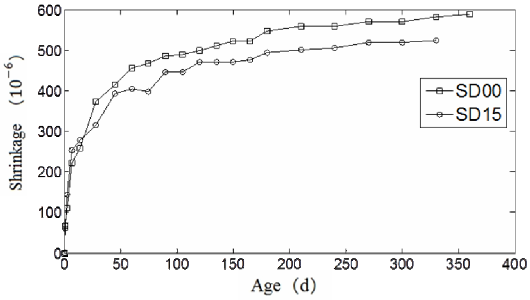


Fig 6 Long time shrinkage

According to the test results, conclusions can be drawn that polymer concrete shows: better properties in terms of permeability and early cracking resistance; better chloride ion permeation resistance (78% higher than regular concrete); no signs of carbonization 28 days after the test which indicates a strong property of resistance; slightly higher early shrinkage rate than regular concrete but lower rate after 45d.

Cement mortar damping test

CSBL is a polymer material, the most significant feature of which is viscoelasticity. The damping mechanism of polymeric material is directly related to its dynamic mechanical relaxation properties. The mechanical part of vibrational energy absorbed by polymeric material is dissipated in the form of heat, through which damping is achieved. Damping property of a material can be expressed with loss factor as shown in Equation (1):

$$\eta = D / 2\pi W = E'' / E' 10^{-6} u\mu\varepsilon \tag{1}$$

In Equation (1)， E'' =loss modulus， E' =storage modulus.

By using dynamic mechanical analyzer (DMA-Q800) and dual cantilever beam method, motar cubes (40mm×10mm×5mm) were tested for its loss factor (temperature: -20^{0}C-40^{0}C; frequency: 1HZ-10HZ). Comparison indicates that the loss factor of SJ00 and SJ15 exhibit similar trend on 1HZ, 3HZ, 5HZ, 10HZ and decreases in order (10HZ: the lowest; 1HZ: the highest). Loss factor comparison on 10HZ is shown in Fig 7.

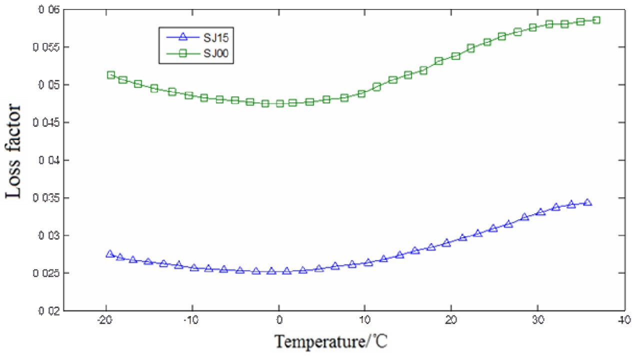
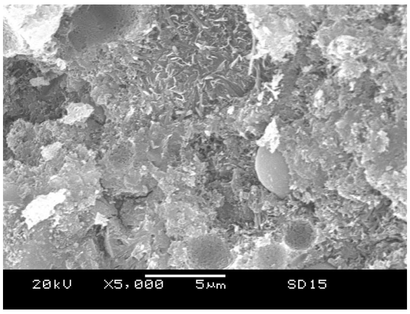


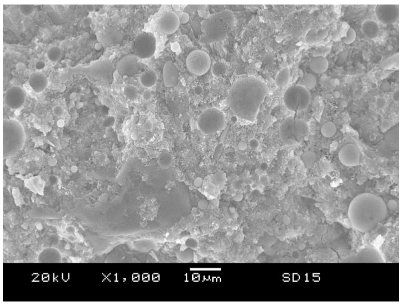
Fig 7 Dissipation modulus on 10 HZ of SJ00 and SJ15

As indicated in Fig 7, the presence of polymer doubled cement mortar's loss factor which means a great increase of damping property.

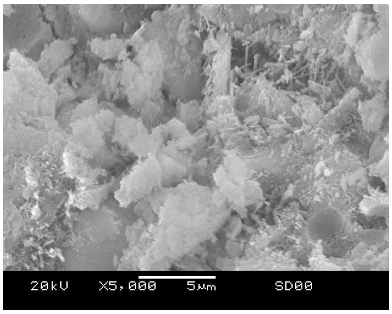
SEM test

The test was done by using JSM-5900LV. A small gilded section of 28d cement mortar was chosen for SEM analysis. Results are shown in Fig 8.





（a）SJ15 5,000x magnification SEM **（b）SJ15 1,000x magnification SEM**



（c）SJ00 5,000x magnification SEM **（d）SJ00 1,000x magnification SEM**

Fig 8 SEM results

As indicated in both 1,000x and 5,000x magnification SEM: fibrous C-S-H of regular cement mortar crosslinks with acicular ettringite crystal, forming discontinuous and reticulated porous skeletal framework; cement mortar with polymer material is producing polymeric membrane, mingling with hydration products of cement and forming densely filled fluffy networks. Such structure is capable of dissipating part of the effects caused by vibrational load in the form of heat, which increases the damping property of cement.

Fatigue test

Test beam specifications are as follow, cross section: 300mm×180mm;length: 4200mm;actual span: 3900.

Beside regular reinforcement, lower part of the beam is equipped with linear prestressed tendons. The cross section and reinforcement are shown in Fig 9.

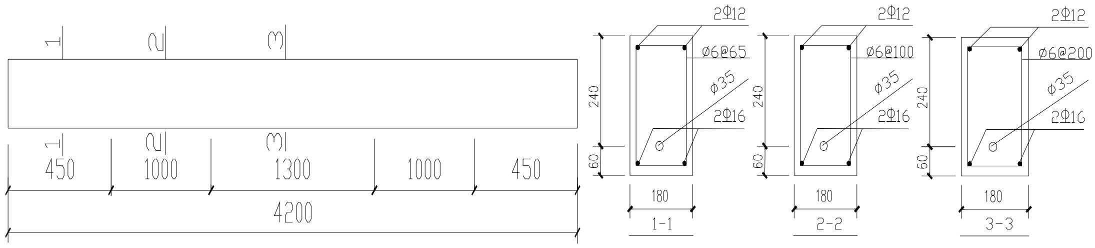


Fig. 9 Experimental beam and cross section

Fatigue test is conducted through third point loading. Upper loading limit equals to the cracking load of the beam, approximately 37kN; lower limit is 6kN ; loading frequency = 6.9Hz.

After 2,000,000 fatigue loading, neither B15 nor B00 were damaged. Cracking trend of both beams are similar: developing fast before 500,000 times loading cycles and stabled afterwards.

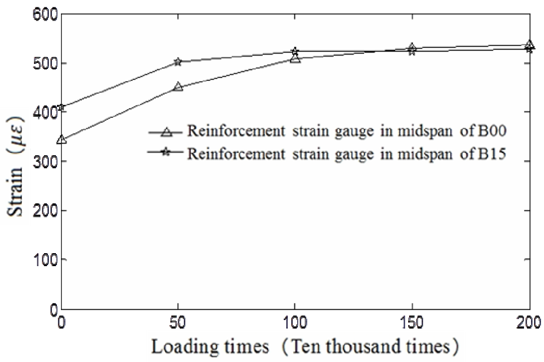


Fig 10 Comparison of steel-strain of B00 and B15

Fig 10 shows the strain pattern of regular steel reinforcements in reaction to fatigue loading. The strain of B00 and B15 increases fast before 500,000 loading cycles and slows down afterwards; very small strains are detected after 1,000,000 cycles; strains become very close to each other after 1,500,000 cycles. It is in line with the patter of cracking development: grows fast before 500,000 cycles and slows down afterwards. Accordingly, adding polymeric material has no impacts on strain development, and the fatigue property of polymer concrete is equal to regular concrete in normal application.

Dynamic test

The test was conducted by applying exciting hammer on the top of beam and 5 acceleration transducers (to record acceleration signals) were evenly distributed in the direction of length. The signals were analyzed by using stochastic subspace identification (SSI). SSI is a widely adopted technique, by which the recorded signals can be analyzed to obtain the structural dynamic characteristics, such as frequencies, mode shapes and damping. Comparing to other signal processing methods, SSI can use only the structural outputs to get useful dynamic information. SSI used here is one featuring reference-based data-driven. The details are referred to (Peeters and Roeck, 1999).

Table 7 Damping ratio of B00 and B15

Test beam	B00	B15
Damping Ration（%）	0.87	1.31

Table 7 shows the damping ratio of BD00 and BD15 (both intact) in the first vibration mode. Results indicate that the damping ratio of polymer concrete beam is 50% higher than regular concrete beam.

Conclusions

Compared to regular concrete:

1）polymer concrete shows slightly lower property in terms of compressive strength and elasticity modulus, but higher rupture strength and tensile splitting strength.

2）Polymer concrete exhibits great improvement in terms of carbonization, chloride ion permeation and early cracking resistance. Its shrinkage is slightly higher in early age than regular cement, but lower after 45d.

3）The loss factor of cement mortar nearly doubled after adding polymeric materials. The dynamic test of prestressed rectangle simple beam indicates that polymeric materials are capable of greatly increase the damping ration of concrete.

4）SEM analysis shows that the compact reticular formation of polymer enfolds cement hydrates, increasing its resistance to environmental erosion and damping property.

5）The fatigue test of prestressed rectangle simple beam shows that the fatigue property of polymer concrete is equal to regular concrete in normal application.

References

Amick H, Monteiro P J M (2005), Modification of concrete damping properties for vibration control in technology facilities. Proceedings of the SPIE-The International Society for Optical Engineering, 5933, pp.1-12.

Cao H，Chen X H，Hua J M, Hu Z M (2011), Tests of Polymer Concrete Used for Structural Vibration Mitigation. Journal of Vibration and Shock, 5, pp.188-191. (in Chinese)

Fu X, Chung D D L (1996), Vibration damping admixtures for cement. Cement and Concrete Research, 26(1), pp. 69-71.

Li X, Chung D D L (1998), Improving silica fume for concrete by surface treatment. Cement and Concrete Research, 28(4), pp. 493-498.

Liu P, Zhou W M (2008), Experimental Study on Damping Property of Polymer Cement. Building Technique Development, 35(7), pp. 26-28. (in Chinese)

Liu T J, Ou J P (2003a), Study on Polymer Cement Mortar Damping Property. New Building Materials, (4), pp. 7-9. (in Chinese)

Liu T J, Ou J P, L J H (2003b), Effects of Silane-treated Silica Fume on Damping Property of Cement Mortar. Journal of the Chinese Ceramic Society, 31(11), pp. 1125-1129. (in Chinese)

National Standard of the People's Republic of China. (2002),Standard for Test Methods of Mechanical Properties of Ordinary Concrete（GB/T 50081-2002）.Beijing：China Architecture & Building Press. (in Chinese)

National Standard of the People's Republic of China. (2009),Standard for Test Methods of Long-term Performance and Durability of Ordinary Concrete（GB/T 50082-2009）. Beijing：China Architecture & Building Press. (in Chinese)

Peeters B, Roeck G D (1999), Reference-based stochastic subspace identification for output-only modal analysis [J]. Mechanical Systems and Signal Processing, 13(6), pp.855-878

Wen S H, Chung D D L (2000), Enhancing the vibration reduction ability of concrete by using steel reinforcement and steel surface treatments, Cement and Concrete Research,30(2), pp. 327-330.

Wan Z Q (2005), Experimental Research and Application of High Damping Concrete in Structural Energy Dissipation and Vibration Mitigation. Master's thesis of Yangzhou University. (in Chinese)

Yao H Y, Liang N X, Sun L J, et al. (2005),Property Study of SD622S Polymer Modified Concrete and the Analysis of Modification Mechanism. Journal of Building Materials, 8(1), pp. 30-36. (in Chinese)