Research on conventional triaxial test of recycled aggregate concrete with PVA fiber

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Abstract. The DYS-2500 high temperature and high pressure rock triaxial testing machine was used to perform regular triaxial compression tests on ordinary concrete recycled aggregate concrete and recycled aggregate concrete mixed with PVA fiber. By changing the recycled coarse aggregate replacement rate of recycled aggregate concrete mixed with PVA fiber (the replacement rates, respectively, are: 0%, 30%, 60%, 100%), the performance of recycled concrete with PVA fiber was compared with conventional recycled aggregate concrete and natural aggregate concrete concerning with its mechanical properties, fracturing process, deformation as well as other characteristics of it. Studies have shown that as the replacement rate of recycled aggregate enhanced, the impact it made on its performance grows. When the replacement rate of recycled aggregate is 30%, after mixing with PVA fiber, the compressive strength of recycled aggregate concrete with PVA fiber is greatly improved, reaching 95% of the compressive strength of natural concrete. When the replacement rate of recycled aggregates is the same as the confining pressure, the peak stress of recycled aggregate concrete samples with PVA fibers is 1.12-1.36 times of ordinary recycled aggregate concrete samples.

1. Introduction

As urbanization and industrialization intensifies in China, quite a few buildings have been demolished, resulting in a large amount of construction waste [1]. At the same time, the need to reconstruct buildings depletes natural resources, triggering a significant increase in the use of natural aggregates. In light of saving natural resources, the promotion of using recycled concrete widely is conducive to sustainable development and environmental protection.

The structure of recycled concrete is much more complicated than natural concrete. There are a lot of micro-cracks in the recycled coarse aggregate. During the rolling process, cracks will appear inside the old cement mortar and between the old aggregate and the mortar. Due to the influence of the micro-cracks in recycled aggregate, the interface transition coefficient of recycled concrete is smaller than that of natural Concrete. The residual mortar contained on the surface of recycled coarse aggregate[2] has low density and high porosity. In Comparison with natural concrete, recycled concrete has lower strength and is more prone to cracking and brittle failure[3]. The PVA fiber has the advantages of environmental protection, hydrophilicity, acid and alkali resistance, and has high
bonding strength with cement and low price. As a concrete modification material, it can improve the flexural capacity and impact resistance of concrete [4].

At this stage, domestic and foreign scholars have done numerous research on recycled concrete and PVA fiber concrete, while there are few studies involving the complex mechanical properties of PVA fiber reinforced recycled concrete uniaxial and triaxial [5-6]. In view of this, based on the understanding obtained by previous scholars on the research reviews of recycled concrete and PVA fiber concrete [7-9], the mechanical properties of PVA fiber recycled concrete under triaxial compression was studied, aiming at different recycled bones. The material replacement rate and the difference between the working performance, mechanical strength and peak stress of recycled concrete mixed with PVA fiber and ordinary recycled concrete under different confining pressures are studied, which provides a reference for the application of recycled concrete in practical engineering.

2. Materials and Testing Procedure

2.1. Experiment material
Sample configuration: using 10mm length of PVA fiber, the appearance is shown in Figure 1, and its physical and mechanical properties are shown in Table 1. The cement is PO32.5R ordinary Portland cement; the natural aggregate is artificial crushed stone, single the grain size of coarse aggregate is 3~10mm, and the continuous gradation: the recycled aggregate is artificially crushed construction waste concrete with the original strength of C30, which is crushed by a jaw crusher and then sieved. The particle size is 3~10mm, continuous gradation; fine aggregate has a sand ratio of 50%, an average particle size of 0.44 mm, and a mud content of no more than 2.5%.

![Figure 1. PVA fiber appearance](image1)

Table 1. PVA fiber performance parameters

| Fiber length (mm) | Tensile strength (MPa) | Fiber diameter (μm) | Density (g/cm³) | Elongation at break (%) | Young's modulus (GPa) |
|------------------|------------------------|---------------------|-----------------|------------------------|------------------------|
| 10               | 1280                   | 21                  | 1.30            | 6                      | 36                     |

2.2. Mixing ratio and specimen preparation
In terms of the performance of PVA fiber-reinforced concrete, the crack control laboratory of Tongji University in the split tensile test of PVA fiber concrete standard specimens is within the range of fiber volume (0.05%-0.38%), which is better than plain concrete under the same conditions. Improved [11-12]; Lin Hui et al. [13] systematically studied the mechanical performance parameters of PVA fiber reinforced concrete, and the experimental conclusions reached the optimal PVA fiber content to enhance the cohesion of cement mortar and improve the compressive performance of mortar; by summarizing the previous scholars’ research on the mechanical properties of PVA fiber reinforced concrete, the strength mechanical model of PVA fiber reinforced recycled concrete [12-13] is obtained, as shown in Figure 2. When the concrete cement content remains unchanged, the PVA fiber content affects the strength of the sample. The MK section is the reinforcement area. PVA fibers are distributed randomly inside the sample to form a network system that can bear the load together with
the concrete to increase the strength of the concrete. The KN section is the weakened area. As the fiber content increases, the cement required to wrap the fiber also increases, the bonding force is weakened, and there are much weak space layers inside. In terms of the strength of concrete, the strength is reduced [13]. Therefore, the content of PVA fiber in this test is determined to be 3.5 kg/m³.

Table 2 shows the mixing ratio of the concrete samples used in this study. Totally, 7 sets of control experiments were set up, NAC stands for ordinary concrete, RC stands for general recycled aggregate concrete, and PRC stands for recycled aggregate concrete mixed with PVA fiber. The number at the end of the number represents the percentage of recycled coarse aggregate replacement rate.

| Numbering | PVA fiber | Natural aggregate | Recycled aggregate | Cement | Water | Sand |
|-----------|-----------|-------------------|--------------------|--------|-------|------|
| NAC       | 0         | 1210              | 0                  | 500    | 210   | 630  |
| PRC30     | 3.5       | 850               | 366                | 500    | 210   | 630  |
| PRC60     | 3.5       | 728               | 482                | 500    | 210   | 630  |
| PRC100    | 3.5       | 0                 | 1200               | 500    | 210   | 630  |
| RC30      | 0         | 845               | 358                | 500    | 210   | 630  |
| RC60      | 0         | 722               | 490                | 500    | 210   | 630  |
| RC100     | 0         | 0                 | 1200               | 500    | 210   | 630  |

2.3. Test equipment and test methods
After all specimens are cured in the standard curing room, they are dried in a natural state, and subjected to uniaxial compression and conventional triaxial compression tests. Figure 3 shows the experimental force model and loading device.

After the specimens are cured in the standard curing room, they are dried in a natural state and tested on the DYS-2500 high temperature and high pressure rock triaxial testing machine. There are 3 types of confining pressures (5MPa, 15MPa, 20MPa) involved.

3. Test Results and Discussion

3.1. Destruction process of specimen
Observing the characteristics of the external cracks and internal failure modes of the specimens, it is found that the failure characteristics of recycled aggregate concrete and recycled aggregate concrete with PVA fibers are similar to those of natural concrete. In uniaxial compression, in the initial loading stage, the internal stress of the specimen increases with the increase in the axial stress of the testing machine, and the stress-strain becomes proportionally increased. When the applied load exceeds the corresponding axial stress, the slope of the curve becomes slower. The growth rate of strain is greater than the increase of stress, and plastic deformation occurs. When the loading force reaches the ultimate strength of concrete, the specimen is immediately crushed. During triaxial compression, the internal structure can withstand greater pressure due to the lateral restraint of the confining pressure on
the specimen. Compared with uniaxial compression, the specimen cracks are relatively small and the crack distribution is more dense; as the replacement rate of recycled aggregate increases, the number of cracks on the specimen gradually increases, and the crack width gradually increases. After mixing PVA fiber, under the same confining pressure and the regeneration rate, because PVA fiber is randomly distributed in the sample, it forms a network system that can bear the load together with the concrete. It is mixed with PVA fiber recycled aggregate concrete compared with conventional recycled aggregate concrete, sample duration is relatively longer and the cracks are relatively finer. Compared with uniaxial compression, during triaxial compression, after the external cracks of the concrete expand, the inside of the sample core continues to bear pressure and is in a triaxial compression state, but as the compressive stress gradually increases, the inside of the core continues to bear pressure The area of concrete is relatively reduced accordingly, and the sample eventually splits and fails.

3.2. Analysis of compressive strength under uniaxial compression
Uniaxial compression test for each type of concrete. The results are shown in Figure 4.

From the stress-strain relationship curve in Figure 4, it can be seen that the strength and elasticity of recycled aggregate concrete mixed with PVA fiber and ordinary recycled aggregate concrete are compared with ordinary natural aggregate concrete. Obviously, adding recycled aggregate will reduce the quality of concrete. After mixing with PVA fiber, the compressive strength of recycled aggregate concrete mixed with PVA fiber is greatly improved when the replacement rate of recycled aggregate is the same; when the replacement rate of recycled aggregate is 30%, it is mixed with PVA fiber recycled aggregate The compressive strength of concrete is particularly improved, reaching 95% of the compressive strength of natural concrete. After adding PVA fibers, because PVA fibers are randomly distributed in the sample to form a network system that can bear the load together with the concrete, the peak strain decreases and the elastic modulus increases accordingly.

3.3. Stress-strain relationship curve
Figure 5 shows the stress-strain relationship curve of recycled concrete mixed with PVA fiber under different confining pressures. It can be seen from the figure that when there is confining pressure, the development trend of the stress-strain curve is gentle and full, with no obvious peak, indicating that the deformation and split development speed of the sample under the action of confining pressure can be effectively controlled. As the confining pressure increases from 5 MPa to 20 MPa, the peak strain interval of the sample will be adjusted. After the peak stress interval, the stress-strain curve shows plastic characteristics, but when the applied load exceeds the corresponding axial stress, when the loading force reaches At the ultimate strength of concrete, the specimen is crushed immediately, that is, the stress-strain curve will drop suddenly. Under the same confining pressure, as the replacement rate of recycled aggregate increases, the principal compressive stress of the specimen decreases, and the axial strain increases accordingly, and the curve trend is basically the same. In the case of the same
recycled aggregate replacement rate, as the confining pressure increases, the principal compressive stress that the specimen can withstand increases correspondingly, and the axial strain also increases accordingly. Compared with conventional recycled aggregate concrete mixed with PVA fibers, the principal compressive stress is relatively increased, and the axial strain is relatively reduced. Under confining pressure, the plastic characteristic time will increase compared with the uniaxial compression experiment. The sample will last longer before it fails.

![Figure 5. Effect of PVA fiber on recycled aggregate under uniaxial compression](image)

3.4. The influence of confining pressure on the mechanical properties of concrete
When the confining pressure is 0 MPa, 5 MPa, 15 MPa, and 20 MPa, the confining pressure and peak stress curves of PVA fiber recycled aggregate concrete and ordinary recycled aggregate concrete are shown in Figure 6.

It can be seen from Figure 6 that under the same confining pressure, as the replacement rate of recycled aggregate increases, the peak stresses of different recycled concretes shows continuous changes, and the peak stresses generally decreases. When the replacement rate of recycled aggregates is the same, with the increase of confining pressure, the peak stress of PRC group and RC group concrete showed a linear increase trend. When the replacement rate of recycled aggregate is the same as the confining pressure, the peak stress of recycled aggregate concrete containing PVA fiber is 1.12-1.36 times that of ordinary recycled aggregate concrete.

![Figure 6. Relation curve between confining pressure and peak stress](image)

4. Conclusions
1. When the replacement rate of recycled aggregate is 30%, the compressive strength of concrete samples mixed with PVA fiber recycled aggregate is greatly improved, reaching 95% of the compressive strength of natural concrete.
2. Under the same recycled aggregate replacement rate, as the confining pressure increases, conventional recycled aggregate concrete mixed with PVA fiber was compared with conventional recycled aggregate concrete, which shows that the principal compressive stress of the two specimens is relatively increased, and the axial strain is relatively decreased. While, compared with the uniaxial compression experiment, the duration of plastic characteristic will be augmented, in this way the specimen will take a longer time to wear off.

3. When the replacement rate of recycled aggregate is equal to the confining pressure rate, the peak stress of the recycled aggregate concrete cylinder containing PVA fiber is 1.12-1.36 times of ordinary recycled aggregate concrete.

References
[1] Qin Zhongfu, Sun Nannan, Wen Haizhen. The application status and research progress of recycled aggregate concrete [J]. Materials Report, 2013, 27(23):142-145.
[2] Zhang Xianggang, Chen Zongping, Xue Jianyang. Experimental study on the physical and mechanical properties of recycled concrete [J]. Bulletin of the Chinese Ceramic Society, 2015, 34(6): 1684-1689.
[3] Liu Xiping, Xue Lijiao, Zhang Keqiang, et al. Basic performance test of recycled concrete with different replacement rates [J]. Journal of Liaoning Technical University, 2014, 33(9): 1270-1274.
[4] Zhao Yanan. Research on the mechanical properties of nanoparticle PVA fiber cement-based composites [D]. Zhengzhou University, 2016
[5] Yuan Yong, Shao Xiaoyun. Development prospects of synthetic fiber reinforced concrete[J]. Concrete, 2000, (12): 3-7
[6] Ahmed S F U, Maalej M, Paramasivam P. Flexural responses of hybrid steel–polyethylene fiber reinforced cement composites containing high volume fly ash. Construction and Building Materials, 2007, 21(5): 1088-1097.
[7] Cheng Xiaoxu, Yang Haozhi. New varieties and uses of synthetic fibers [M]. Beijing: Textile Industry Press, 1998
[8] Hu Zuming, Liu Zhaofeng, Qian Guozhong, etc. High-strength polyvinyl alcohol fiber and its application in composite materials [J]. Industrial Textiles, 1998, (2): 30-33
[9] Goldfein S. Fibrous Reinforcement for Portland Cement, Modern Plastics, 1965, 42(8): 156-160
[10] Ministry of Electric Power Industry of the People's Republic of China, Ministry of Water Resources of the People's Republic of China. DLJ204—81SLJ2—81 Rock Test Regulations for Water Conservancy and Hydropower Engineering [S]. Beijing: Water Resources Press, 1982.
[11] Shao Xiaoyun. Experimental study on the performance of PVA fiber reinforced concrete flexural members [D]. Master's degree thesis. Shanghai: Tongji University, 2001.7
[12] Zhang Zhaoqiang. Experimental study on conventional triaxial compression of concrete mixed with PVA fiber [J]. Concrete and Cement Products, 2018(7): 51-54.
[13] Lin Hui. Research on the mechanical and deformation properties of PVA fiber concrete[D]. Master's degree thesis. Nanjing: Nanjing University of Aeronautics and Astronautics, 2006.12
[14] Wang Hailong. Research on conventional triaxial test of recycled concrete with surface layer [J]. Concrete and Cement Products, 2017(7): 70-73.