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Stress-Strain relationship of Glass-Polyviny Alcohol Fiber Reinforced Recycled Coarse Aggregate Concrete under Uniaxial Compression

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Abstract: In order to improve the mechanical properties of recycled concrete, glass fiber and polyvinyl alcohol fiber were added into recycled concrete as reinforcement. An experimental about uniaxial compression tests for glass-polyviny alcohol fiber reinforced recycled coarse aggregate concrete was carried out. The factors considered in the experiment include the replacement rate of recycled coarse aggregate, volume content of polyvinyl alcohol fiber and glass fiber, and different method of fiber incorporation. According to the tested stress-strain curves, the different concrete compression toughness index and elastic modulus were calculated. Experimental results showed that the uniaxial compressive strength of recycled aggregate concrete was lower than that of natural aggregate concrete; however, recycled concrete mixed fiber can significantly improve uniaxial compressive strength, compressive toughness index and elastic modulus. There was an optimal content of glass fiber or polyvinyl alcohol fiber. When the replacement rate of recycled coarse aggregate was 50%, the improvement of uniaxial compressive strength and elastic modulus of recycled concrete by adding two kinds of fiber was better than that by adding single fiber. The above results can provide technical reference for the engineering application and popularization of fiber reinforced recycled concrete.

Keywords: recycled coarse aggregate; glass fiber; polyvinyl alcohol fiber; compression toughness index; stress-strain relationship

1. Introduction

At present, China's urbanization process is gradually accelerating, resulting in the accumulation and landfill of construction waste has become increasingly prominent problems, and the application and development of recycled concrete technology provides a strong support for the recycling of construction waste[1]. However, the recycled coarse aggregate has many deficiencies, such as high crushing index, low aggregate hardness and large porosity, which restrict the application of recycled concrete[2]. Existing research results show that the fiber incorporation can significantly improve the mechanical properties of recycled concrete, mainly because the fiber can bear part of the internal stress and delay or prevent the emergence and development of internal cracks[3-4]. At present, the commonly used fibers in engineering include polyvinyl alcohol fiber, polypropylene fiber, basalt fiber, glass fiber and steel fiber. The single fiber can only improve the performance of concrete in one aspect. The addition of steel fiber will improve the compressive bearing capacity and toughness of concrete, but steel fiber has disadvantages such as easy corrosion, high bulk density and poor working performance [5-7]. Basalt fiber has a good connection with cement stone interface and presents a good closed space network structure in the concrete matrix material[8-9], but has little effect on the compressive strength of concrete[10-11].

Polypropylene fiber can improve the toughness and post-peak ductility of concrete under uniaxial compression, and reduce its stiffness degradation and stress deterioration, but has little influence on its peak strength and elastic modulus[12].Polyvinyl alcohol fiber can improve the deformation ability and toughness of concrete, and improve the brittle failure of concrete[13-15]. Glass fiber reinforced concrete has excellent mechanical properties such as tensile resistance, bending resistance and crack resistance[16-17]. Therefore, in this paper, polyvinyl alcohol fiber and glass fiber were mixed into recycled concrete to improve the deformation ability and crack resistance of concrete respectively. The influence of glass-polyvinyl alcohol fiber on the stress-strain relationship of recycled concrete under uniaxial compression was studied through uniaxial compression test, which provides technical reference for the engineering application of recycled concrete in the future.

2. Test Overview

2.1 Test materials

P•O42.5 type cement was used in the test. The density of fly ash and S95 mineral powder produced by a power plant is 2180kg/m^3 and 2890kg /m^3 respectively. Medium sand with fineness modulus of 2.78. Natural aggregate (NA) is 5 ~ 25mm gravel particle size. Recycled coarse aggregate (RA) from solid waste comprehensive treatment center, water absorption rate 6.3%, apparent density 2630kg/m^3, crushing index 21.2%. According to the Chinese Code "Recycling Coarse Aggregate for Concrete" [18], it is determined that RA belongs to Ш grade of recycled coarse aggregate. The water reducer agent is Q8081PCA polycarboxylic acid high performance water reducer, and the water is city tap water.

The fibers are BX-00114 glass fiber (GF) produced by a limited company with a density of 0.91 g/cm^3, a length of 9mm, a diameter of 12mm, and a ultimate tensile strength of not less than 1200 MPa. The polyvinyl alcohol fiber (PVA-F) produced by a limited company has a density of 1.27 g /cm^3, a length of 9mm, a diameter of 15 mm, and the ultimate tensile strength is not less than 1500 MPa.

2.2 Test design and mix ratio

This test is divided into 13 groups, with 3 specimens in each group. The fiber content and RA replacement rate of each test group is shown in Table 1. The first three groups are the reference groups of concrete without fiber. The concrete mix ratio of reference groups is shown in Table 2.

Tab. 1 Design of concrete test group

Specimen	Fiber length/mm	Fiber content/%		Replacement of recycled aggregate/%
		GF	PVA-F	
NC	--	--	--	0
R_1C	--	--	--	50
R_2C	--	--	--	100
R_2G-1	9	0.30	--	100
R_2G-2	9	0.45	--	100
R_2G-3	9	0.60	--	100
R_2P-1	9	--	0.05	100
R_2P-2	9	--	0.10	100
R_2P-3	9	--	0.15	100

R_1G	9	0.45	--	50
R_1P	9	--	0.10	50
R_2GP	9	0.45	0.10	100
R_1GP	9	0.45	0.10	50

Tab.2 Mixproportion of concrete （kg/m^3）

Specimen	Cement	Fly ash	Mineral powder	Water	Sand	NA	RA	water reducer agent
NC	431.3	61.6	123.2	165	589	1047.14	0	8.84
R_1C	431.3	61.6	123.2	165	589	523.57	523.57	8.84
R_2C	431.3	61.6	123.2	165	589	0	1047.14	8.84

2.3 Test methods

2.3.1 Uniaxial compression test

After concrete mixing, standard specimens of 150mm×150mm×300 mm were poured. After forming, the specimens were cured in a constant temperature curing room for 28d. After taking them out and drying, strain gauges were pasted in the middle span of each side of the specimens.

WAW-2000 microcomputer controlled electro-hydraulic servo pressure testing machine and UT7260 static resistance strain collecting instrument were used for the test. Data collection device was shown in Figure 1, which collected data four times per second.

Fig.1 Uniaxial compression test

2.3.2 Elastic modulus

The secant modulus between the origin and $0.4f_c$ point on the uniaxial compressive stress-strain full curve is taken as the elastic modulus of recycled concrete, and the calculation formula is:

$$E_c = \frac{f_{0.4} - 0.5}{\varepsilon_{0.4} - \varepsilon_0}$$

Where，E_c—Modulus of elasticity /MPa；

$f_{0.4}$—The stress value corresponding to the 40% uniaxial compressive strength；

$\varepsilon_{0.4}$—$0.4f_c$corresponding to the concrete strain value；

ε_0 —The initial stress is the strain value corresponding to 0.5MPa.

2.3.3 Compression toughness index

Concrete toughness is generally defined as the capacity of the energy absorbed by the failure of concrete specimen under load, which is usually expressed by the area enclosed by the stress-strain curve or the load-deflection curve with the abscissa, also known as toughness. The compression toughness index of fiber reinforced concrete specimens was calculated by referring to the relevant formulas in the Chinese Code of Test Methods for Steel Fiber Reinforced Concrete[19]. The peak stress f_c and the critical stress $0.85f_c$ were determined in the stress-strain curve (Fig. 2). The point 0.85 f_c on the vertical axis was used to cross the stress-strain curve on the horizontal axis at point A, and the strain corresponding to point A was ε_0. Take O as the origin and mark the D point corresponding to 3 times ε_0 on the horizontal axis. According to formula (1), the compression toughness index of different types of fiber recycled concrete was calculated.

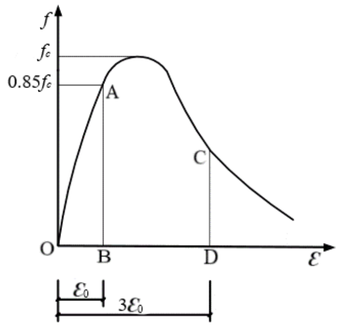


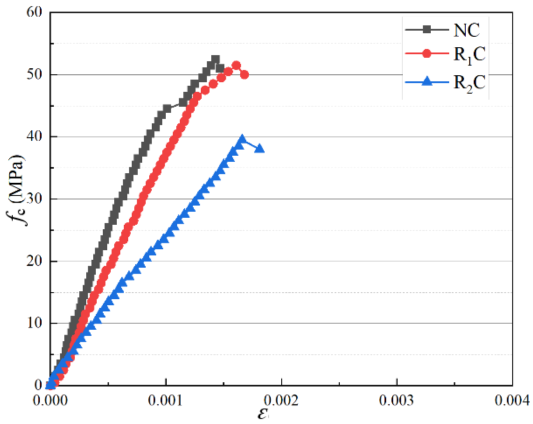
Fig.2Stress-strain curve under compression

$$\eta_c = S_{OACD} / S_{OAB} \tag{1}$$

3. Test results and analysis

3.1 Stress-strain curve

Fig. 3 shows the compressive stress-strain curve of reference concrete without fiber. As can be seen from Figure 3, the stress-strain curve only has the ascending section, because once the concrete cracks, the elastic energy accumulated in the loading system during the loading process will be released sharply, causing the crack to expand rapidly and the specimen to be destroyed immediately, so the descending section of the stress-strain curve cannot be measured.



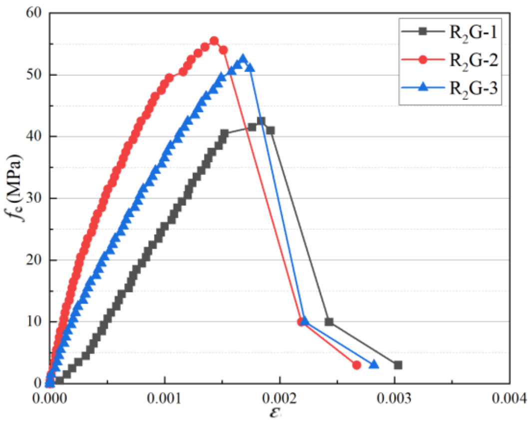
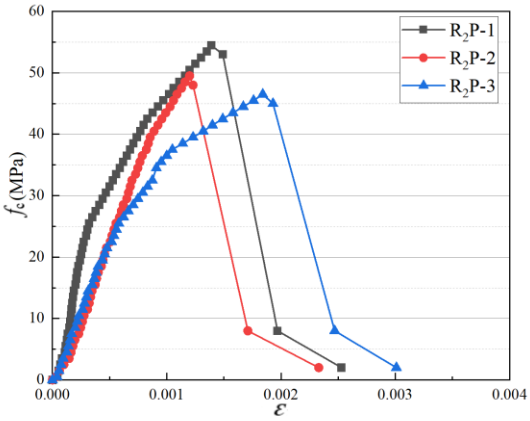


Fig.3 Compression stress-strain curve of reference concreteFig.4 Compression stress-strain curve of glass fiber concrete

The stress-strain curve of recycled concrete (R_1C) with 50% recycled coarse aggregate replacement rate is close to the peak stress of normal concrete (NC), but the slope of R_1C stress-strain curve is slightly smaller and the peak strain is slightly larger. The peak stress and slope of the stress-strain curve of recycled concrete (R_2C) with the replacement rate of 100% recycled coarse aggregate are significantly reduced. The main reason is that the recycled coarse aggregate has a higher crushing index and its own strength is insufficient, so the strength of recycled concrete is reduced. In addition, the microcosmic structure of recycled concrete and natural aggregate concrete exists obvious difference, because inside the concrete interface belongs to the porous structure of loose, is a relatively weak link in the concrete, because of recycled coarse aggregate surface cling to the old cement paste or mortar, has affected the new bond between aggregate and cement matrix, and increased the recycled concrete internal old interface, As a result, the recycled concrete has a large deformation in the process of compression, so the slope of the ascending section of the stress-strain curve decreases.

See Fig.4 for the stress-strain curves of recycled concrete with different volume content GF. It can be seen from Figure 4 that the glass fiber volume content has a great influence on the shape of the curve. Compared with R_2G-1 and R_2G-3, the stress-strain curve of specimen R_2G-2 is fuller, and the ascending section is steeper, indicating a larger elastic modulus, while the descending section is gentter, indicating a higher ductility. Therefore, when the volume content of glass fiber is close to 0.45%, the reinforcement effect on the uniaxial compression performance of recycled concrete is better.



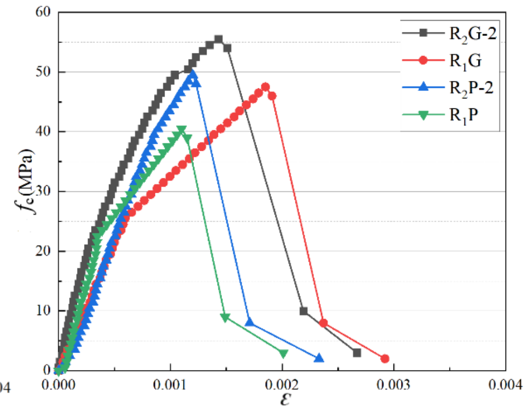


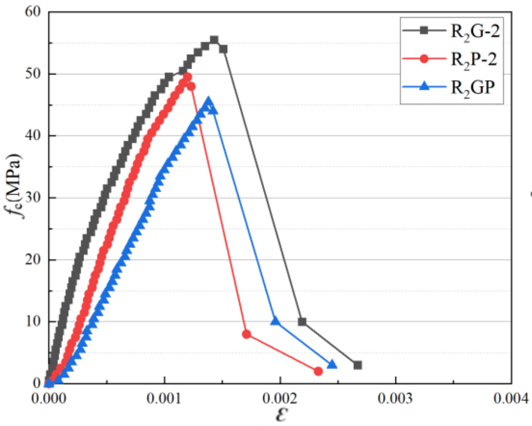
Fig.5

Compression stress-strain curve of PVA-F concrete

Fig.6 Compression stress-strain curve of concrete

Fig.5 shows the compressive stress-strain curve of recycled concrete with different volume content of PVA-F. As can be seen from Fig.5, with the increase of the content of PVA fiber, the uniaxial compressive strength gradually decreases and the slope of the stress-strain curve decreases to some extent. It shows that the enhancement effect of PVA fiber with lower content on the uniaxial compressive strength and elastic modulus of recycled concrete with 100% replacement rate is more obvious.

The compressive stress-strain curves of GF and PVA-F recycled concrete with different replacement rates of recycled coarse aggregate are shown in Fig.6. By comparing the stress-strain curves of R_2G-2 with R_1G, it can be seen that the slope and peak stress of the stress-strain curve of R_2G-2 are both higher than that of R_1G, indicating that the reinforcement of the uniaxial compressive strength and elastic modulus of concrete with 100% recycled coarse aggregate replacement rate is better than that of concrete with 50% recycled aggregate replacement rate. By comparing the stress-strain curves of R_2P-2 and R_1P, it can be seen that PVA fiber has a similar effect on recycled concrete.



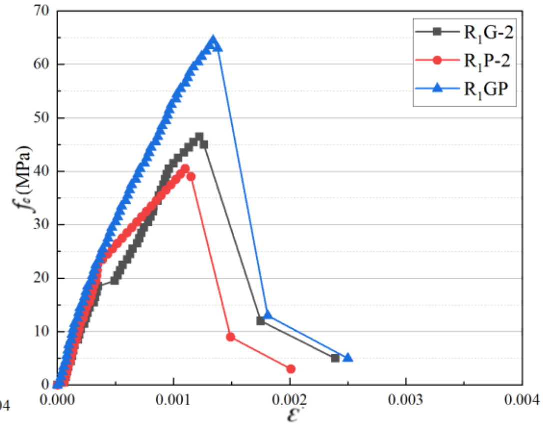


Fig.7 stress-strain curve of 100% recycled concreteFig.8 stress-strain curve of 50% recycled concrete

Fig. 7 shows the compressive stress-strain curve of recycled concrete with 100% recycled coarse aggregate replacement rate mixed with GF and PVA-F. As can be seen from Fig. 7, after glass fiber and polyvinyl alcohol fiber were mixed, the uniaxial compressive strength and slope of the stress-strain curve of R_2GP of the specimen were both reduced compared with that of R_2G-2 and R_2P-2 of the specimen with single fiber. The main reason is that the recycled coarse aggregate absorbs a lot of water in the concrete mixing process, which leads to the lack of concrete mixing water. When the two kinds of fibers are mixed, a large number of fibers are difficult to disperse, which aggravates the winding of the fibers into balls, leading to the increase of weak areas in the internal interface of concrete, and the occurrence of negative fiber hybrid effect, so the uniaxial compressive strength is reduced.

The compressive stress-strain curve of recycled concrete mixed with GF and PVA-F with 50% recycled coarse aggregate replacement rate is shown in Fig.8. As can be seen from Fig.8, the uniaxial compressive strength of the stress-strain curve of R_1GP specimens after mixing glass fiber and polyvinyl alcohol fiber is significantly higher than that of R_1G-2 and R_1P-2 specimens with single fiber. The possible reason is that the recycled coarse aggregate in the recycled concrete with 50% replacement rate is relatively small, the mixing water loss is reduced in the concrete mixing process, and the mixing of the two fibers is easy to disperse evenly, which is conducive to the positive mixing effect of the fibers, so the uniaxial compressive strength is improved.

3.2 Compression toughness index

The compression toughness index of different types of fiber recycled concrete is shown in Table 3.

Tab.3Compression toughness index of concrete

Specimen	S_{OAB}	S_{OACD}	η_c
NC	0.0243	0.0464	1.9114
R_1C	0.0256	0.0498	1.9469
R_2C	0.0252	0.0394	1.5604
R_2G-1	0.0225	0.0614	2.7334
R_2G-2	0.0274	0.0807	2.9492
R_2G-3	0.0322	0.0729	2.2632
R_2P-1	0.0292	0.0709	2.4316
R_2P-2	0.0200	0.0532	2.6572
R_2P-3	0.0290	0.0764	2.6339

R_1G	0.0276	0.0807	2.9204
R_1P	0.0194	0.0492	2.5426
R_2GP	0.0202	0.0499	2.4627
R_1GP	0.0309	0.0744	2.4115

As can be seen from Table 3, the compression toughness index η_c of NC, R_1C and R_2C of the reference concrete is all between 1 and 2, and the toughness is poor. Compared with R_2C specimen with 100% recycled coarse aggregate replacement rate without fiber, the compression toughness index η_c increases by 75.2%, 89.0% and 45.0% with the increase of the volume content of glass fiber alone. The compressive toughness index η_c increases by 55.8%, 70.3% and 68.8%, respectively, with the increase of the volume content of PVA fiber. When the replacement rate of recycled coarse aggregate is 50%, the compression toughness index of single-doped polyvinyl alcohol fiber R_1P and single-doped glass fiber R_1G is increased by 30.6% and 50.0%, respectively, compared with that of non-fiber R_1C. The results indicate that the addition of glass fiber or polyvinyl alcohol fiber can significantly improve the toughness of recycled concrete, and the increase of 100% recycled coarse aggregate replacement rate of concrete is greater than that of 50% recycled coarse aggregate replacement rate of concrete.

R_2G-2 and R_2P-2 (γ=100%), R_1G and R_1P (γ=50%) were higher in compression toughness index than R_2GP and R_1GP, but R_2GP and R_1GP of the two groups of R_2G and R_1GP were compared with R_2C and R_1C. The compression toughness index was still increased by 57.8% and 23.9%. The possible reason is that the fiber content in the hybrid fiber recycled concrete is too much, and the two types of fibers do not show good synergistic effect.

3.3 Modulus of elasticity

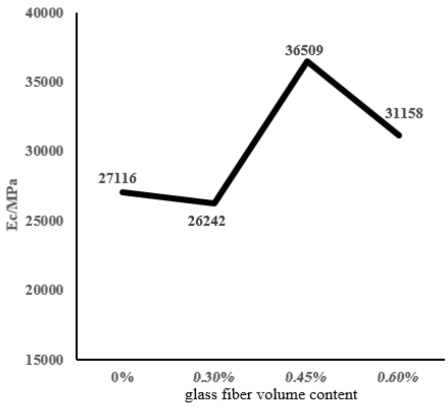


Fig.9 Relationship between E_c and glass fiber content

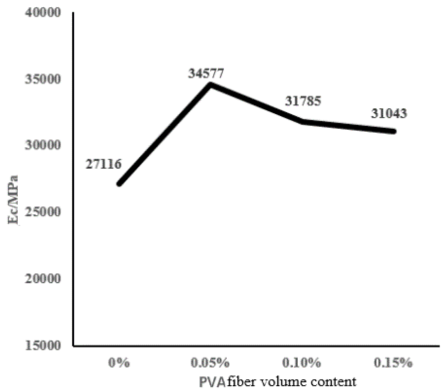


Fig.10 Relationship between E_c and PVA fiber content

The relationship between elastic modulus, GF content and PVA-F content is shown in Fig. 9 and Fig. 10. When the volume content of glass fiber is 0.30%, 0.45% and 0.60%, respectively, the elastic modulus increases by -3.2%, 34.6% and 14.9%. Therefore, when the volume content of glass fiber is close to 0.45%, the elastic modulus of recycled concrete can be significantly increased. When the volume content of polyvinyl alcohol fiber is 0.05%, 0.10% and 0.15%, respectively, the elastic modulus increases by 27.5%, 17.2% and 14.5%. Therefore, when the volume content of polyvinyl alcohol fiber is close to 0.05%, the elastic modulus of recycled concrete can be significantly increased.

The elastic modulus of fiber reclaimed concrete with 50% and 100% recycled coarse aggregate replacement rate is shown in Fig. 11 and Fig. 12, respectively. As can be seen from Figure 11, when the replacement rate of recycled coarse aggregate is 50%, the elastic modulus of recycled concrete improved by mixing the two fibers is significantly higher than that of glass fiber or polyvinyl alcohol fiber alone, indicating that the two fibers show a good synergistic effect. As can be seen from Fig.12, when the replacement rate of recycled coarse aggregate is 100% and the two fibers are mixed into recycled concrete, the elastic modulus is lower than that of single-fiber mixed concrete and even about 5% lower than that of without fiber mixed recycled concrete. The possible reason is that a large number of low-strength old mortar is attached to the surface of recycled coarse aggregate and its adhesion to aggregate is poor. When all recycled aggregate is used and the fiber content is large, the interface effect of concrete will be increased. When the interface effect is dominant, the elastic modulus will be reduced.

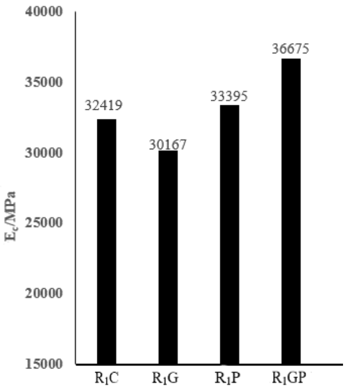


Fig.11 Elastic modulus of 50% recycled concrete

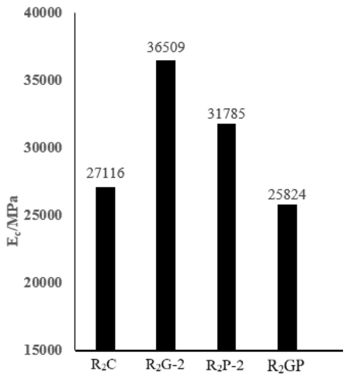


Fig.12 Elastic modulus of 100% recycled concrete

4. Conclusion

(1) The compressive strength of recycled concrete is slightly lower than that of natural aggregate concrete. The addition of glass fiber or polyvinyl alcohol fiber can significantly improve the compressive strength and plastic deformation ability of recycled concrete, and the stress-strain curve has a downward section.

(2) The compressive strength, compressive toughness index and elastic modulus of recycled concrete can be significantly improved when glass fiber or polyvinyl alcohol fiber is mixed with 0.45% and 0.05% by volume content, respectively.

(3) When the replacement rate of recycled coarse aggregate is 50%, the improvement of compressive strength and elastic modulus of recycled concrete by mixing two kinds of fibers is better than that by adding glass fiber or polyvinyl alcohol fiber alone. Therefore, it is suggested to select 50% recycled coarse aggregate replacement rate when the mixed fiber recycled concrete is constructed.

(4) When the replacement rate of recycled coarse aggregate is 100%, the improvement of compressive strength, compressive toughness index and elastic modulus of recycled concrete by adding glass fiber or polyvinyl alcohol fiber alone is better than that by mixing the two kinds of fiber.

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