

Research Article

Ting Wang[#], Shenao Cui[#], Xiaoyu Ren[#], Weishen Zhang, Xuechao Yang, Shangwei Gong, Deqiang Yang, Bangxiang Li, Wengang Zhang, Tian Su*, Xuefeng Mei*, Xiaoming Dong, Liancheng Duan, Zhiyuan Ma, Xueyun Cao, and Xiyao Yu

Study on the mechanical properties and microstructure of recycled brick aggregate concrete with waste fiber

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Abstract: Recycled concrete technology can promote the sustainable development of the construction industry, but the insufficient mechanical properties of recycled concrete have become a key constraint on its development. By adding waste fibers, the mechanical properties of recycled concrete can be improved, and the problem of disposing of waste polypropylene fibers can be solved. In this article, the effects of recycled brick aggregate content and waste fiber content on the mechanical properties and microstructures of recycled brick aggregate concrete through macroscopic mechanical experiments and microstructure experiments are investigated. The results show that the addition of recycled brick aggregate reduces the mechanical properties of concrete; when the content of recycled brick aggregate is 100%, the compressive

strength and splitting tensile strength decrease by 22.04 and 20.00%, respectively. The addition of waste fibers can improve the mechanical properties of recycled brick aggregate concrete, but it is necessary to control the contents of waste fibers in a certain range. When the content of waste fibers is 0.08%, the best improvement effect on the mechanical properties of concrete is achieved; the compressive strength of concrete with a 50% (100%) recycled aggregate replacement rate increases by 6.06% (8.90%), while the splitting tensile strength of concrete with a 50% (100%) recycled aggregate replacement rate increases by 2.30% (6.16%). Through microstructural analysis, the mechanism by which waste fiber improves the mechanical properties of recycled brick aggregate concrete is revealed. The addition of waste fibers has the effect of strengthening the framework inside the recycled brick aggregate concrete, forming a good structural stress system and allowing the recycled brick aggregate concrete to continue to bear loads after cracking. In this study, waste brick aggregate and waste fiber are effectively utilized, which can not only reduce pollution to the environment but also realize the sustainable utilization of resources.

[#] These authors contributed equally to this work and should be considered first co-authors.

* **Corresponding author: Tian Su**, School of Civil Engineering and Geomatics, Shandong University of Technology, Zibo, 255000, China; Department of Engineering and Management, International College, Krirk University, No. 3 Soi Ramintra 1, Ramintra Road, Anusaowaree, Bangkok, Bangkok 10220, Thailand, e-mail: sutian@sduet.edu.cn

* **Corresponding author: Xuefeng Mei**, School of Civil Engineering and Geomatics, Shandong University of Technology, Zibo, 255000, China, e-mail: xfmei@my.swjtu.edu.cn

Ting Wang, Shenao Cui, Xiaoyu Ren, Weishen Zhang, Xuechao Yang, Shangwei Gong, Deqiang Yang, Bangxiang Li, Wengang Zhang: School of Civil Engineering and Geomatics, Shandong University of Technology, Zibo, 255000, China

Xiaoming Dong, Liancheng Duan, Zhiyuan Ma: Zibo Xintiansheng Concrete Co., Ltd, Intersection of Beijing Road and Gengci Avenue in Fujia Town, Zhangdian District, Zibo, Shandong, 255185, China

Xueyun Cao: Xingtai Construction Group Co., Ltd, No. 7 Yijinhualuo East Street, Dongsheng District, Ordos, Inner Mongolia, 017010, China

Xiyao Yu: China Water Resources Beifang Investigation, Design and Research Co., Ltd, 60 Dongting Road, Hexi District, Tianjin, 300222, China

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1 Introduction

In recent years, the construction industry has developed rapidly, and concrete has been widely used as the main building material [1]. In the process of building reconstruction and expansion, a large amount of construction waste is generated [2], mainly including waste concrete and waste clay bricks [3,4]. With the improvement of human awareness of environmental protection, the impact of construction waste on the environment has attracted increasing attention [5]. In addition, concrete is composed of sand and stone aggregate, so the exploitation of natural sand and stone is

very large [6]. As a nonrenewable resource, natural sand and stone tend to be depleted [7], and the contradiction between the increasing demand for concrete and the gradual shortage of aggregate has become increasingly prominent [8,9]. Therefore, it is necessary to reuse construction waste [10].

Recycled brick aggregate has high water absorption, many pores, low strength, and other shortcomings [11], resulting in its crushing index and water absorption being higher than those of natural stone aggregate [12]. When using waste bricks as coarse aggregate to prepare recycled concrete, the brick aggregate should be prewetted to reach the saturated surface dry state to avoid the impact of high aggregate water absorption on concrete performance [13]. Many scholars have studied the mechanical properties of recycled brick aggregate concrete through a large number of tests and verified the feasibility of its application in engineering [14,15]. It can be seen from the mechanical property test that the failure mode of recycled brick aggregate concrete was not significantly different from that of natural stone aggregate concrete [16]. However, when the replacement rate of recycled brick aggregate was large, the failure mode of concrete began to develop toward ductile failure [17]. When the replacement rate of brick coarse aggregate was small, the splitting tensile and flexural strength of recycled brick aggregate concrete was similar to that of natural stone aggregate concrete [18,19]. When the replacement rate of brick coarse aggregate was large, its mechanical properties were lower than those of ordinary concrete [20,21], and the deterioration of compressive strength was more significant [22]. In addition, the water–cement ratio also affected the mechanical properties of brick aggregate concrete. With the increase in the replacement rate of recycled brick aggregate, the mechanical properties of brick aggregate concrete with a low water–cement ratio decreased more significantly [23].

The interface transition zone was the weak area inside the concrete, and its performance had a significant impact on the mechanical properties of the concrete. When the brick aggregate was broken, the attached mortar on its surface almost fell off, so the interface transition zone of recycled brick aggregate concrete was only the interface transition zone of aggregate and mortar [24]. Due to the large roughness of brick aggregate, its adhesion to mortar was relatively high, and the interface transition zone between aggregate and mortar was denser [25]. Therefore, for brick aggregate concrete, the interfacial transition zone is no longer its weak link, and low-strength brick aggregate becomes a key factor affecting the mechanical properties of concrete [26]. Zheng [27] conducted experimental research on the mechanical properties of recycled stone aggregate concrete and recycled brick aggregate concrete, and the results showed that the mechanical properties of recycled brick

aggregate concrete were inferior to those of recycled stone aggregate concrete. Rahman and Ahmad [28,29] found that if all recycled brick aggregates were used as coarse aggregates, the recycled brick aggregate concrete would not achieve the target compressive strength. Kibriya [30] found that if stone aggregate and clay brick aggregate were used to make mixed aggregate concrete, its mechanical properties would be ideal. Zhu *et al.* [31] pointed out that as the replacement rate of recycled brick aggregates increased, the mechanical properties of concrete showed a downward trend, which was due to the high water absorption and high porosity of recycled brick aggregates. Meng *et al.* [32] pointed out that the addition of brick aggregate increased the deformation capacity of concrete, and the apparent change in concrete volume during loading led to changes in the failure mode of concrete. The existing research has focused on the mechanical properties of recycled brick aggregate concrete [33,34], while research on how to improve the mechanical properties of recycled brick aggregate concrete is relatively scarce.

Due to the low mechanical properties and durability of recycled concrete, scholars began to improve its performance by adding fibers [35]. Steel fibers [36,37], oxide fibers [38], coconut fibers [39,40], and glass fibers [41] can play positive roles in improving the performance of concrete. The incorporation of fibers can improve the internal defects of recycled concrete, reduce the possibility of stress concentration, and make the recycled concrete more evenly stressed [42]. In addition, the distribution of fibers in concrete could assist in changing the propagation path of microcracks under external loads, thereby inhibiting the development of cracks [43].

On the other hand, China is the largest textile producer in the world, producing a large number of textile products every year. Polypropylene fiber is widely used in the production of clothing fabrics and other textiles due to its low density and high strength [44,45]. At present, a large number of waste textiles with polypropylene fiber as the main material are produced every year. Considering the cost factor, waste textiles are generally treated by direct burial or reclamation, which causes great pollution to the ecological environment.

Polypropylene fiber has the characteristics of good acid and alkali resistance, light weight, and no water absorption [46]. As a reinforced fiber of concrete, it could improve the internal defects of concrete materials [47] and then improve the mechanical properties and durability of concrete [48]. However, Ghosni *et al.* [49] reported that the compressive strength of concrete containing 1.0% propylene type carpet waste fiber was lower than that of concrete without fibers. Abdul *et al.* [50] found that the addition of polypropylene-based recycled polyester fiber could

Table 1: Cement properties

	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)		Flexural strength (MPa)		Volume stability
			3 days	28 days	3 days	28 days	
P.O42.5	183	248	22.2	47.3	4.9	7.8	Satisfy

reduce the concrete compressive strength. When the fiber content was 0.5, 1.0, 1.5, and 2.0%, the concrete compressive strength decreased by 8.5, 31.6, 37.5, and 45.9%, respectively. However, the addition of fibers could improve the fracture toughness of concrete. It is worth noting that waste fibers in bundles or cutting shapes reduced the concrete compressive strength. The fiber length and the fiber content should be controlled within a certain range when adding fiber to improve the performance of concrete. When the fiber length was 30 mm, the compressive strength of the concrete was the best; when the fiber length was 19 mm, the splitting tensile strength was the best [51,52]. At present, there are relatively few studies on the mechanical properties of recycled brick aggregate concrete, and most of them fail to clarify the mechanism of the effect of waste fiber on the mechanical properties of recycled concrete.

The existing research has focused on the mechanical properties of recycled stone aggregate concrete with waste fiber, while research on the application of waste fiber in recycled brick aggregate concrete is relatively scarce. In this article, the effects of recycled brick aggregate content and waste fiber content on the mechanical properties and microstructure of recycled brick aggregate concrete were investigated by macroscopic mechanical experiments and microstructure experiments, and a strength calculation model of recycled brick aggregate concrete mixed with waste fiber was obtained. This study can effectively utilize waste brick aggregate and waste fiber, which can not only

reduce pollution to the environment but also realize the sustainable utilization of resources, promote the sustainable development of the construction industry, and have good economic, social and environmental benefits.

2 Test materials and methods

2.1 Test materials

The cement used in this test is P.O 42.5 Ordinary Portland Cement [53] provided by Shandong Zibo Luzhong Cement Co., Ltd. The specific properties are shown in Table 1. The ordinary coarse aggregate was natural crushed stone. The recycled brick aggregate was red brick discarded in a demolition project in Zibo, Shandong Province. The production process of recycled brick aggregate is shown in Figure 1. The properties of the coarse aggregate are shown in Table 2. The distribution curve of common coarse aggregate and recycled brick aggregate is shown in Figure 2. The waste fiber was the waste polypropylene door mat produced by Ningbo Huiduo Weaving Co., Ltd, which was disassembled manually. The waste doormat was manually disassembled and then made into 19 mm fibers for use. The detailed production process is shown in Figure 3. The fine aggregate was natural river sand with a fineness modulus of 2.9, and the distribution curve is shown in Figure 4.

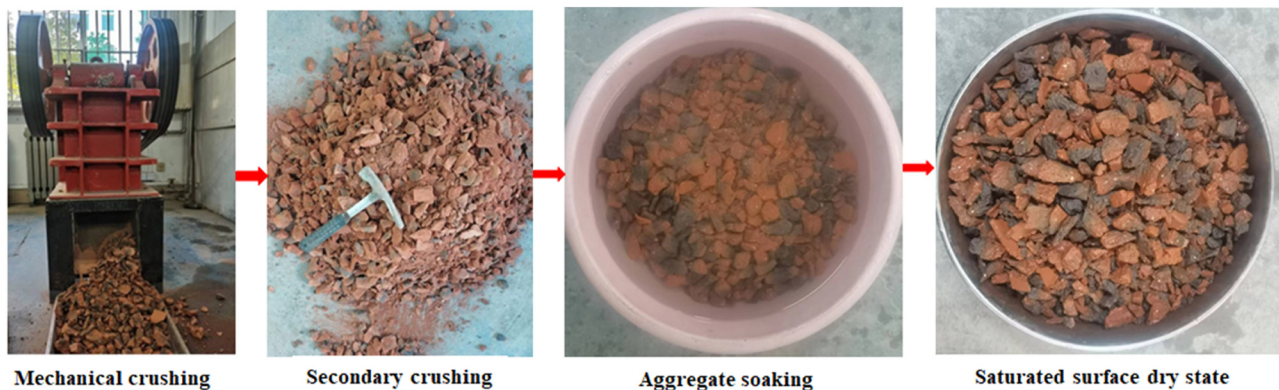
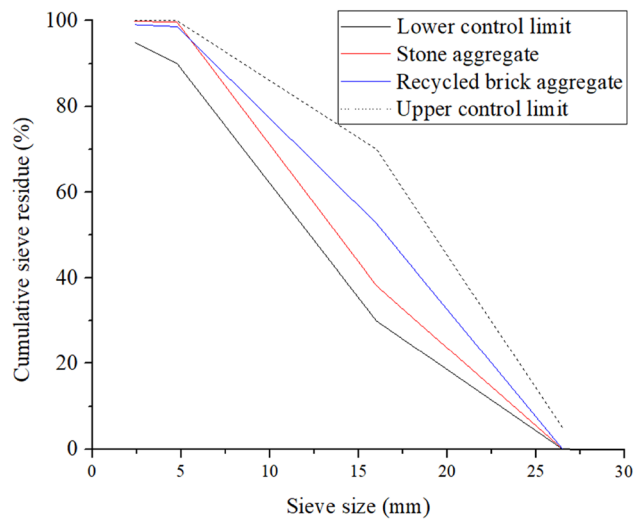
**Figure 1:** Production process of recycled brick aggregate.

Table 2: Coarse aggregate properties

Aggregate type	Particle size (mm)	Apparent density ($\text{g}\cdot\text{cm}^{-3}$)	Crush index (%)	Water absorption (%)
Stone aggregate	5–25	2.711	8.70	1.10
Brick aggregate	5–25	2.226	27.90	16.50

**Figure 2:** Distribution curve of common coarse aggregate.

2.2 Concrete mix design

The concrete mix design is shown in Table 3. To ensure the uniform distribution of waste fibers in the concrete, the dry mixing method was adopted in this experiment. First, the sand and coarse aggregate were loaded into the mixer for dry mixing for 1 min and then mixed with cement and waste fibers for 5 min. Finally, water was added and fully stirred for 5 min.

2.3 Mechanical property test program

The mechanical properties of concrete specimens were tested according to the Ordinary Concrete Mechanical Properties Test Method Standard GB50081-2016 [54]. The compressive strength and splitting tensile strength of concrete

cube specimens ($100\text{ mm} \times 100\text{ mm} \times 100\text{ mm}$) were tested by a microcomputer-controlled electrohydraulic servo pressure testing machine (Figure 5).

2.4 Microstructure test program

The microstructure observation sample was cut into a suitable size by a cutting machine to ensure that the observed surface of the sample was smooth. After drying at 60°C for 24 h in the oven, the microstructure observation samples were subjected to gold plating. The samples were observed by field emission environmental scanning electron microscopy (Quanta 250 FEG) at different magnifications, as shown in Figure 6.

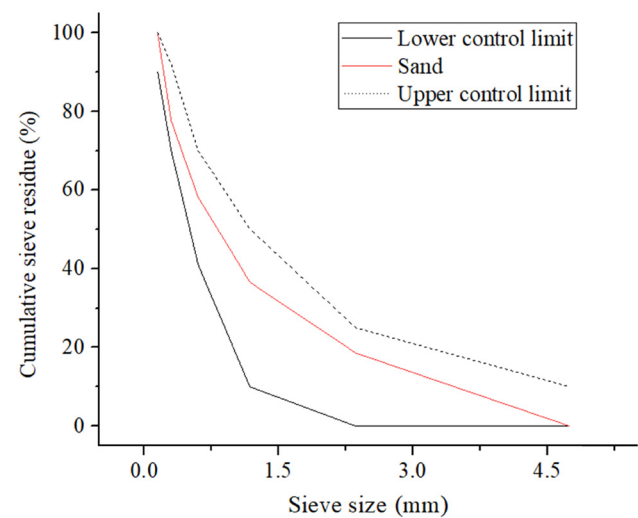
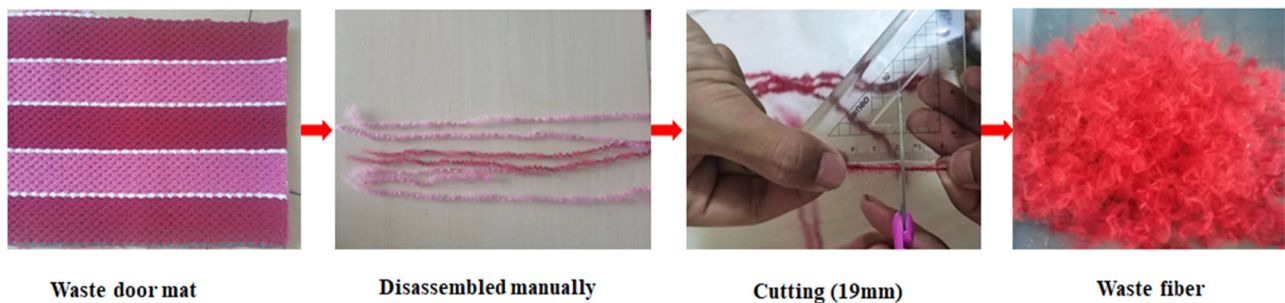
**Figure 4:** Distribution curve of natural river sand.**Figure 3:** Production process of waste fiber.

Table 3: Concrete mix design ($\text{kg}\cdot\text{m}^{-3}$)

Specimen number	Water	Cement	Sand	Natural stone	Recycled brick	Waste fiber
P	175	350	700	1,140	0	—
B25	175	350	700	855	234	—
B50	175	350	700	570	468	—
B75	175	350	700	285	702	—
B100	175	350	700	0	936	—
X1B50	175	350	700	570	468	0.728
X2B50	175	350	700	570	468	1.092
X3B50	175	350	700	570	468	1.456
X1B100	175	350	700	0	936	0.728
X2B100	175	350	700	0	936	1.092
X3B100	175	350	700	0	936	1.456

Note: Here P represents ordinary aggregate concrete, B represents recycled brick aggregate concrete, the numbers after B represent the replacement rate of brick aggregate, X represents waste fiber, and the numbers 1, 2, and 3 represent 0.08, 0.12, and 0.16% fiber volume addition, respectively.

3 Results and discussion

3.1 Failure mode

3.1.1 Failure mode of the compressive specimen

The compressive failure mode of the concrete specimen is shown in Figure 7. The compressive failure rule and failure mode of recycled brick aggregate concrete were consistent with those of ordinary aggregate concrete. However, unlike ordinary aggregate concrete, the failure interface of recycled brick aggregate concrete included interfacial transition zone

failure and brick aggregate fracture failure. The reason for this phenomenon was that when the concrete was subjected to an external load, the transition interface first produced stress concentration [55] and microcracks, and then the microcracks continued to develop. Due to the low strength of the recycled brick aggregate, it could not resist the development of cracks and was cut off; the stone had a high strength, which could hinder the development of cracks, change the crack development direction, and make cracks develop along the transition interface between the mortar and aggregate. The compressive strength of ordinary aggregate concrete was affected by the strength of cement mortar and the strength of the interfacial transition zone

**Figure 5:** Electrohydraulic servo pressure testing machine.



Figure 6: Field emission environmental scanning electron microscopy.

between mortar and aggregate, while the compressive strength of recycled brick aggregate concrete was affected by the recycled brick aggregate strength, which was similar to the research results of Ji [16], Zhu [20], and Ji [26].

The irregular distribution of waste fibers effectively inhibited the development of cracks in recycled brick aggregate concrete and maintained its integrity. The cracks were mainly distributed around the main cracks, and the crack width was obviously reduced. This trend was basically consistent with the conclusion obtained by Zhou *et al.* [52]. In addition, the broken part of recycled brick aggregate concrete mixed with waste fiber did not easily fall off after being damaged. The failure mode of brick aggregate concrete with waste fiber was more complex than recycled

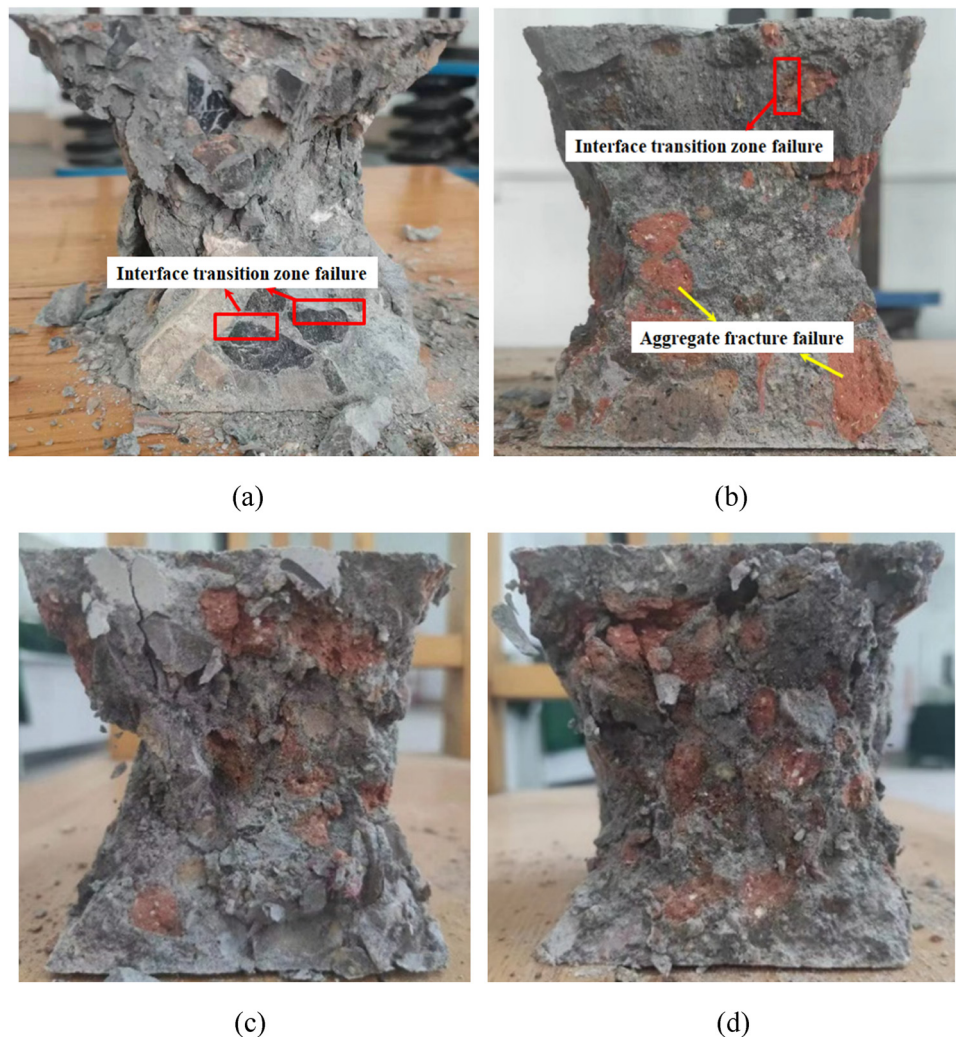


Figure 7: Compressive failure modes: (a) P, (b) B100, (c) X2B50, and (d) X2B100.

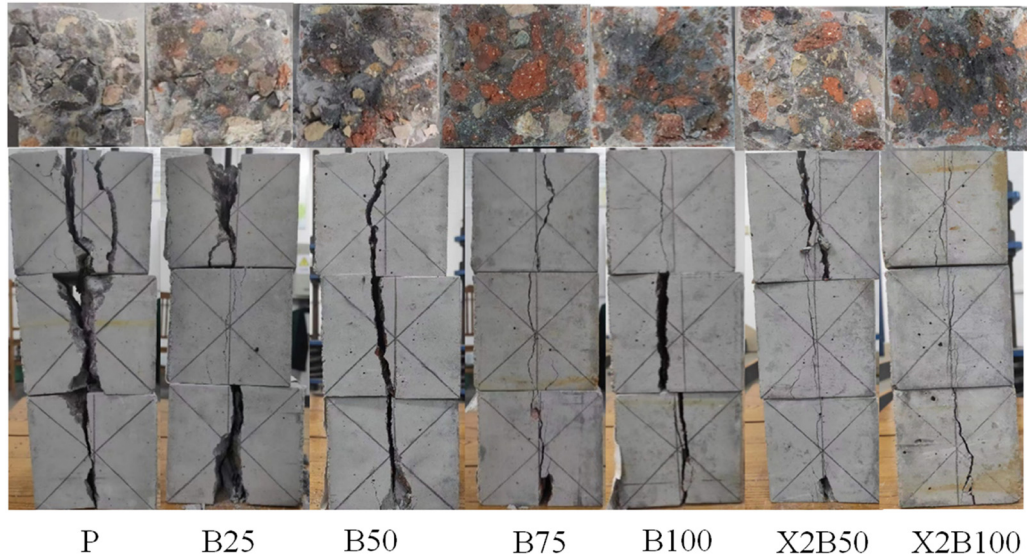


Figure 8: Splitting tensile failure modes.

brick aggregate concrete without waste fiber, including aggregate fracture failure and aggregate cataclastic failure.

3.1.2 Failure mode of splitting tensile specimens

The splitting tensile failure mode of the concrete specimen is shown in Figure 8. For ordinary aggregate concrete, the stone aggregate strength was higher than that of cement stone. When the stone was on the stress surface, the stone transferred the shear force to the surrounding cement stone, causing damage to the cement stone, while the stone was not damaged. With the increasing replacement rate of brick aggregate, the failure surface became increasingly flat due to the weak shear resistance of brick aggregate; additionally, it failed to change the crack development direction, resulting in a flatter failure surface than before. Therefore, the splitting tensile strength of recycled brick aggregate concrete mainly depended on the amount of brick aggregate at the stress interface [20,26].

The failure interface of recycled brick aggregate concrete with waste fiber was similar to that of recycled brick aggregate concrete, and there was only an obvious crack development trace at the stressed zone; this finding indicated that the fiber transferred the load at the stressed zone to the surrounding region, and it improved the splitting tensile strength of concrete to a certain extent. However, the development of concrete cracks was relatively rapid, and the elastic moduli of concrete and fiber were quite different, which could not effectively bear the tensile stress. Therefore, the improvement of the splitting tensile capacity of concrete by waste fiber was relatively limited.

3.2 Compressive strength analysis

The relationship between the compressive strength of concrete and the replacement rate of recycled brick aggregate is shown in Figure 9. With the increase in the replacement rate of recycled brick aggregate, the compressive strength gradually decreased, and the downward trend was increasingly obvious. When the replacement rates of recycled brick aggregate were 25, 50, 75, and 100%, the compressive strengths decreased by 9.97, 7.72, 18.92, and 22.04%, respectively. The reasons for this situation were as follows. On

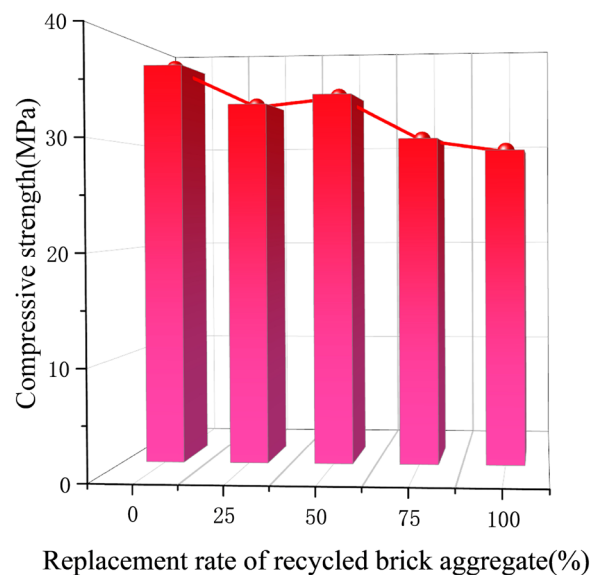


Figure 9: Relationship between compressive strength and replacement rate.

the one hand, the characteristics of recycled brick aggregate, such as a high crushing index and low strength, made the concrete highly prone to stress concentration under compression, resulting in the compressive strength of recycled brick aggregate concrete being lower than that of ordinary aggregate concrete [55]. On the other hand, the recycled brick aggregate was soaked before use, which improved the effective water–cement ratio to a certain extent; moreover, cement hydration slowed in the later period of concrete curing, and the water absorbed by the recycled brick aggregate in the early stage was gradually released, improving the effective water–cement ratio of the recycled brick aggregate concrete [56] and reducing the strength of the concrete.

Notably, the compressive strength of concrete with a 25% recycled brick aggregate replacement rate was lower than that with a 50% replacement rate. The reason for this effect was that the distribution of recycled brick aggregate and natural stone aggregate in concrete had a certain randomness. When the replacement rate of recycled brick aggregate was different, the impact of aggregate on the stress state of concrete was distinct [57]. In a reasonable range of replacement rates of recycled brick aggregate, the compressive strength of recycled brick aggregate concrete would increase with increasing replacement rate. This result was consistent with the views of Ji [16], Ge *et al.* [58], and Wang *et al.* [59].

The relationship between the compressive strength of concrete and the waste fiber content is shown in Figure 10. Adding waste fiber could effectively improve the compressive strength of recycled brick aggregate concrete. When

the fiber content was 0.08%, the compressive strength of concrete with a 50% (100%) recycled aggregate replacement rate increased by 6.06% (8.90%). This phenomenon occurred because the waste fiber could not only hinder the development of cracks but also restrict the transverse deformation of the middle part of concrete, thus improving the compressive strength of concrete. The effect of waste fiber on the compressive strength of concrete with a 100% recycled brick aggregate replacement rate was better than that with a 50% recycled brick aggregate replacement rate. This effect occurred because the higher the brick aggregate content was, the smaller the elastic modulus of concrete, and the closer the elastic modulus of waste fiber was, the better the synergistic deformation. However, when the fiber content was too high, the compressive strength of concrete was reduced. This result occurred because when the fiber content was too high, the fibers in the concrete are prone to aggregation and uneven dispersion, leading to the poor local hydration reaction of concrete, reducing the fluidity of concrete, reducing the compactness of concrete, and reducing the compressive strength of concrete [52].

3.3 Splitting tensile strength analysis

The relationship between the splitting tensile strength of concrete and the replacement rate of recycled brick aggregate is shown in Figure 11. Figure 11 shows that the splitting tensile strength decreased with increasing recycled brick aggregate content. Compared with ordinary aggregate

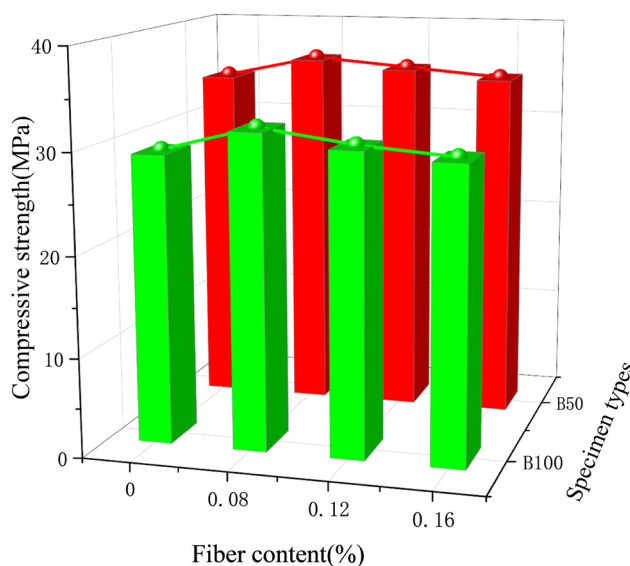


Figure 10: Relationship between compressive strength and waste fiber content.

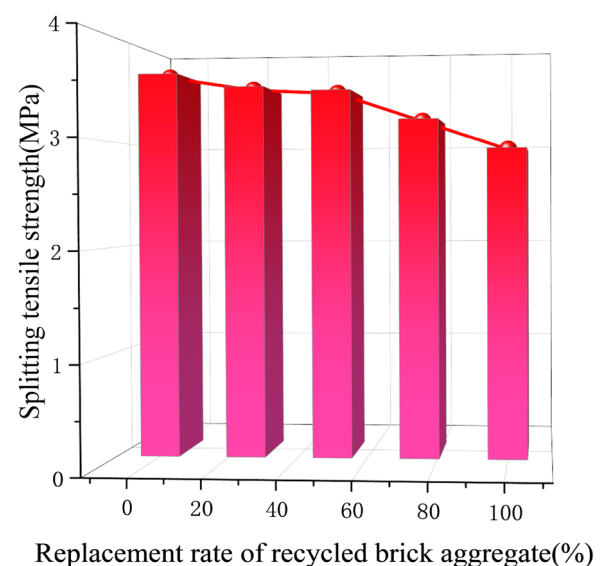


Figure 11: Relationship between splitting tensile strength and replacement rate.

concrete, the splitting tensile strength of concrete with recycled brick aggregate replacement rates of 25, 50, 75, and 100% decreased by 3.56, 4.65, 12.33, and 20.00%, respectively. When the replacement ratio of brick aggregate was less than 50%, the splitting tensile strength decreased slowly, but when the replacement ratio of brick aggregate was more than 50%, the splitting tensile strength decreased gradually and significantly. This phenomenon occurred mainly due to the weak shear resistance of brick aggregate, and the brick aggregate on the shear surface was cut directly, reducing the shear strength of concrete. Therefore, the splitting tensile strength mainly depended on the content of brick aggregate in the shear section. The more brick aggregate that was in the shear section, the lower the splitting tensile strength of the concrete [60].

The relationship between the splitting tensile strength of concrete and the waste fiber content is shown in Figure 12. Figure 12 shows that adding waste fiber could effectively improve the splitting tensile strength of recycled brick aggregate concrete. This is similar to the results obtained by Zhou [52]. When the fiber content was 0.08%, the splitting tensile strength of concrete with a 50% (100%) recycled aggregate replacement rate increased by 2.30% (6.16%). This effect occurred because the waste fiber could increase the toughness of concrete stress zone. When the concrete produced microcracks, the fiber would produce tensile stress to hinder the development of cracks [43].

3.4 Concrete strength calculation model

From the experimental results, there was a good linear relationship between the concrete strength and the replacement rate of recycled brick aggregate. Therefore, the linear regression method was used to fit the relationship between them. The relationship between the concrete strength and the replacement rate of recycled brick aggregate (r) was fitted as follows (Figure 13):

$$\text{Compressive strength: } y = -0.0789r + 36.782, \quad (1) \\ R^2 = 0.8932$$

$$\text{Splitting tensile strength: } y = -0.0071r + 3.710, \quad (2) \\ R^2 = 0.9234$$

From the experimental results, there was a nonlinear relationship between concrete strength and the waste fiber content; thus, the relationship between them was obtained through nonlinear fitting. The relationship between the concrete strength and the waste fiber content (x) was fitted as follows (Figure 14):

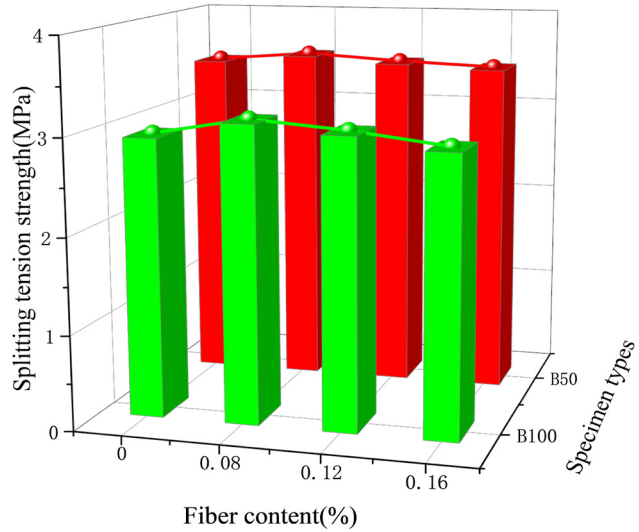


Figure 12: Relationship between splitting tensile strength and waste fiber content.

$$\text{Compressive strength (B50):} \\ y = -262.78x^2 + 44.08x + 34.364, \quad R^2 = 0.8932 \quad (3)$$

$$\text{Splitting tensile strength (B50):} \\ y = -12.216x^2 + 1.7705x + 3.4824, \quad R^2 = 0.9234 \quad (4)$$

$$\text{Compressive strength (B100):} \\ y = -318.04x^2 + 51.926x + 29.066, \quad R^2 = 0.8932 \quad (5)$$

$$\text{Splitting tensile strength (B100):} \\ y = -28.125x^2 + 4.325x + 2.922, \quad R^2 = 0.9234 \quad (6)$$

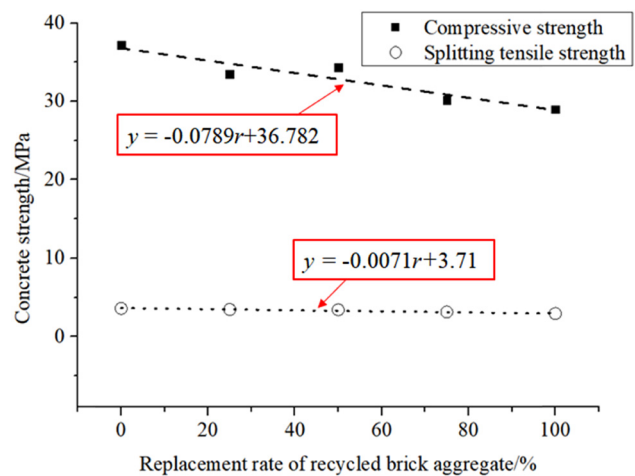


Figure 13: Strength fitting curve of recycled brick aggregate concrete.

3.5 Microstructure analysis

3.5.1 Microscopic morphology of concrete without waste fiber

The microscopic morphologies of ordinary concrete and recycled brick aggregate concrete are shown in Figure 15. Figure 15 shows that the surface of the stone aggregate was smooth with few pores and cracks, while the surface of the recycled brick aggregate was rough with many pores and cracks. From the interfacial transition zone, the boundary between the stone aggregate and cement mortar in ordinary concrete was clear, while the boundary between the brick aggregate and cement mortar in recycled aggregate concrete was vague, and some cement hydration products filled the surface pores of the brick aggregate; this phenomenon indicated that the cement mortar in ordinary concrete adhered to the stone aggregate, while the cement mortar in recycled brick aggregate concrete flowed into the pores and cracks of the brick aggregate to form a whole component. Therefore, the bond strength between brick aggregate and cement mortar was better than that between stone aggregate and cement mortar.

Figure 15 shows that with the increase in brick aggregate content, the hydration products of concrete gradually loosened, and the number of pores gradually increased. Although hydration products such as C-S-H and Aft were generated, the distribution gradually dispersed, failing to effectively fill microcracks and pores. This phenomenon occurred because as the replacement rate of brick aggregate increased, the actual water-cement ratio of concrete increased, the

hydration products loosened, the porosity increased, and the density decreased.

In addition, Figure 15(a) shows that there were relatively few hydration products on the surface of the water sac in the interfacial transition zone, and a large amount of $\text{Ca}(\text{OH})_2$ was generated. This effect occurred because various particles in the freshly mixed concrete settled unevenly. Under the action of gravity, the cement particles settled, and the water moved upward. The aggregate prevented the upward movement of water; therefore, water formed a water sac at the lower part of the aggregate, and a large amount of Ca^{2+} generated during the hydration of cement particles was carried into the water sac and enriched, forming an interfacial transition zone. After the completion of the cement hydration reaction, the water in the water sac was consumed, forming a cavity and producing stress concentration; moreover, $\text{Ca}(\text{OH})_2$ did not easily bear stress due to the special hexagonal flake, resulting in the degradation of the mechanical properties of concrete [61,62].

3.5.2 Microscopic morphology of recycled brick aggregate concrete mixed with waste fiber

The microscopic morphology of recycled brick aggregate concrete mixed with waste fiber is shown in Figure 16. Figure 16 shows that the addition of waste fiber had no obvious effect on the interfacial transition zone of recycled brick aggregate concrete because waste fiber did not participate in the hydration reaction. The effects of waste fiber on concrete were as follows: On the one hand, the addition

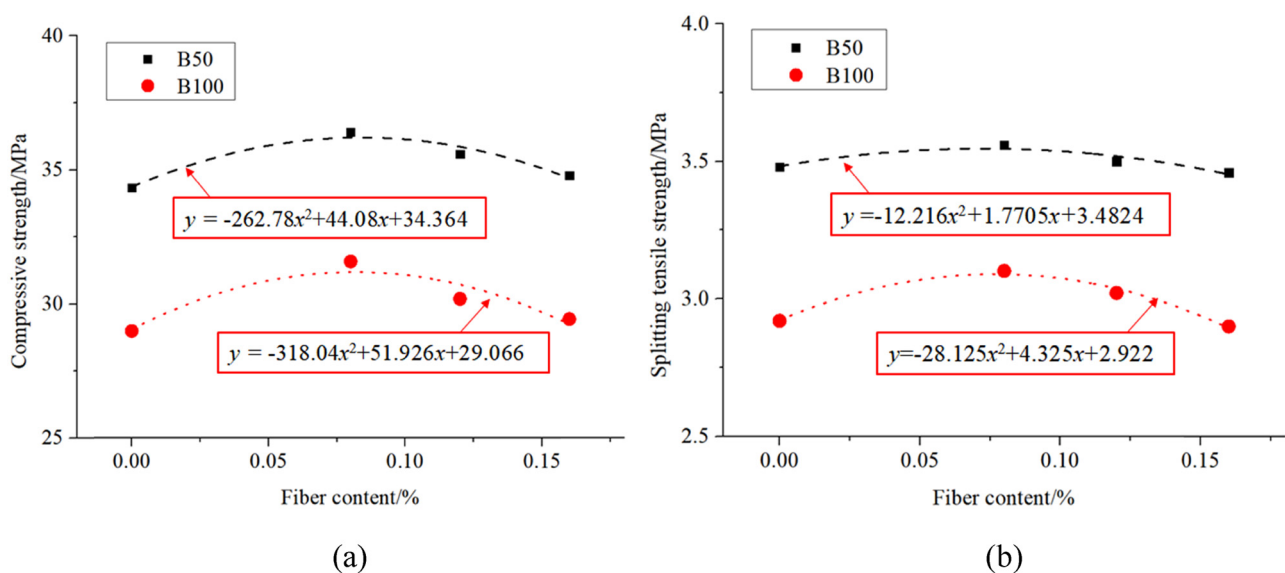


Figure 14: Strength fitting curve of recycled brick aggregate concrete with waste fiber.

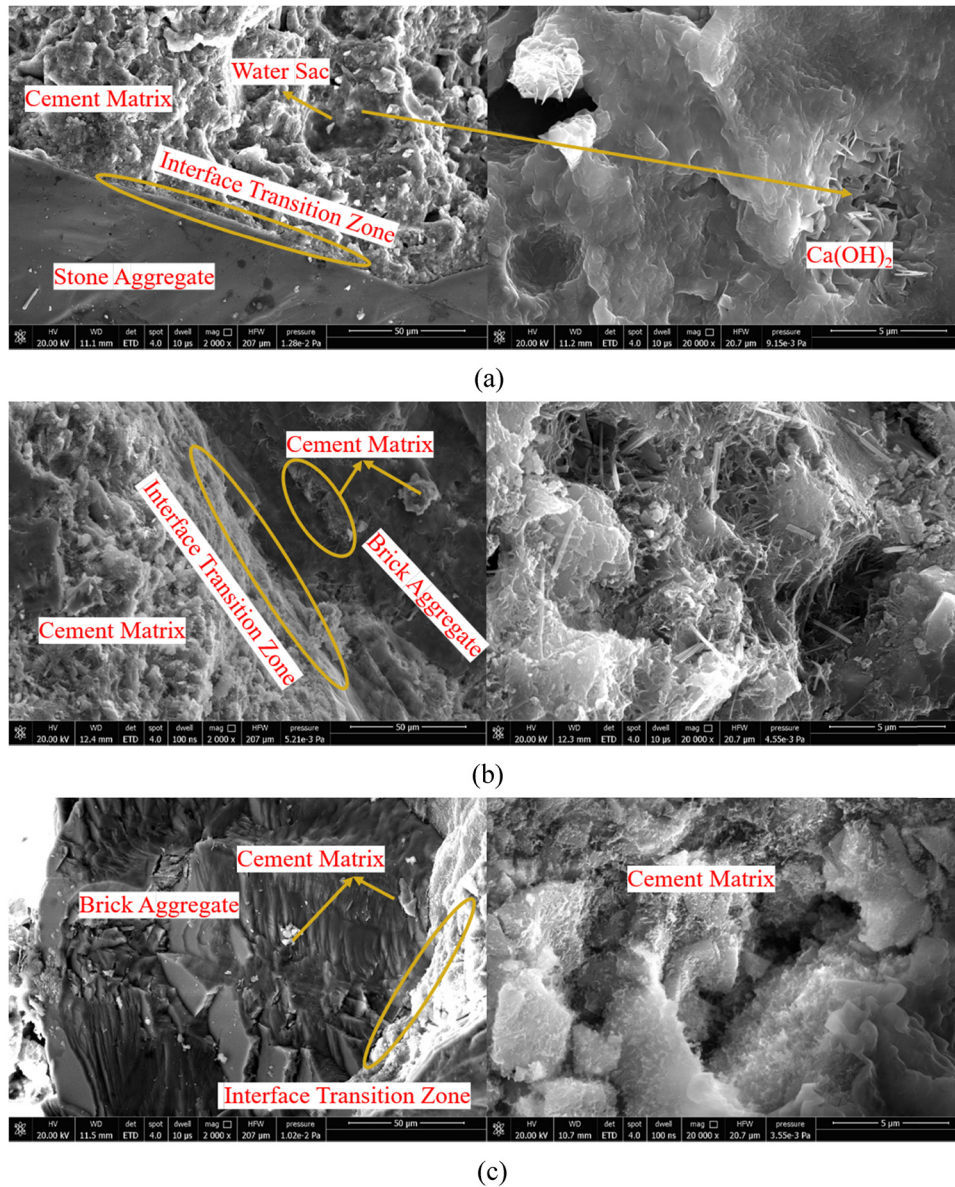


Figure 15: Microscopic morphology of concrete: (a) P, (b) B50, and (c) B100.

of waste fiber affected the distribution of cement and water in cement mortar and reduced the uniformity of the distribution of cement and water, which led to additional water that did not participate in the hydration reaction and finally formed holes. On the other hand, the waste fiber had good bonding performance with cement stone, which hindered the development of pores and cracks. Waste fiber would hinder the development of pores and cracks and form a three-dimensional skeleton structure after being uniformly dispersed in concrete, thereby improving the compressive strength and reducing the shrinkage of recycled concrete.

3.6 Reinforcement mechanism of waste fiber on recycled brick aggregate concrete

During mixing and vibrating, the waste fibers were distributed in the concrete and overlapped to form an irregular frame structure (Figure 17). With the flow of cement mortar, the fiber frame structure was filled with recycled brick aggregate, which reduced the internal defects and improved the continuity. When subjected to external force, the waste fibers and the recycled brick aggregate were deformed together. The implicated effects of waste fibers made recycled brick aggregate concrete continue to bear

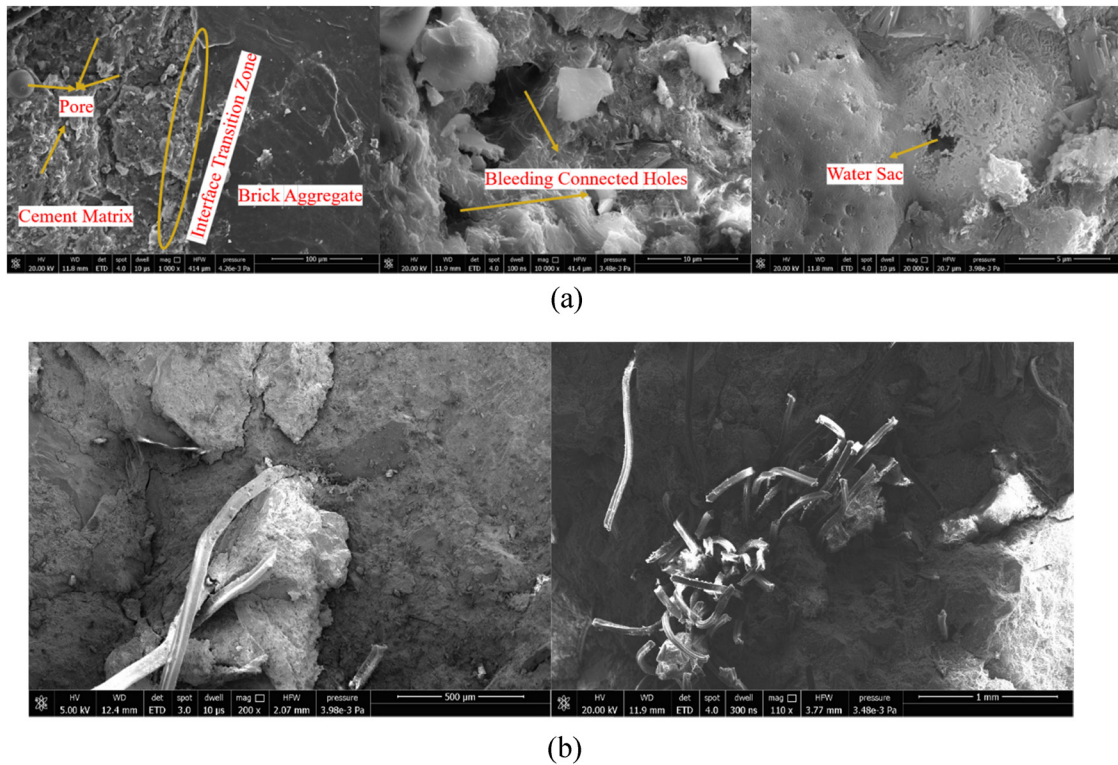


Figure 16: Microscopic morphology of concrete with waste fiber: (a) X2B50 and (b) X3B50.

load after cracking, thus improving the mechanical properties of concrete [63].

In addition, the incorporation of waste fibers produced a frame enhancement effect inside the recycled brick aggregate concrete, which inhibited the floating of small recycled brick aggregate, reduced the strength difference between the upper and lower parts of the specimen, and formed a good structural stress system, thereby improving

the overall stiffness and mechanical performance of the concrete [64].

Moreover, the surface of the recycled brick aggregate was rough and multiangular, which increased the friction force and mechanical bite force between the recycled brick aggregate and waste fiber and could prevent the waste fiber from being pulled out when stressed, thereby improving the mechanical properties of the concrete.

For recycled brick aggregate concrete, waste fiber inhibited the development of concrete cracks so that its strength could be improved to a certain extent. However, the addition of excessive waste fibers increased the initial defects of concrete. When the influence of the initial defects of concrete was greater than the contribution of waste fibers to the strength of concrete, the addition of fiber reduced the strength of concrete. Therefore, the amount of waste fibers added should be controlled within a reasonable range and evenly distributed.

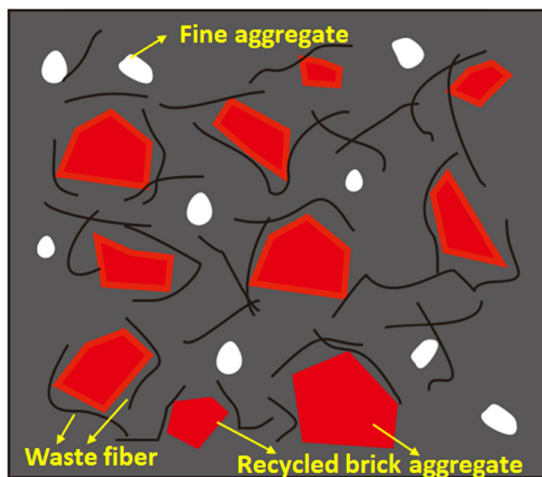


Figure 17: Distribution diagram of waste fiber in concrete.

4 Conclusions

- 1) The addition of recycled brick aggregates reduced the mechanical properties of concrete. As the replacement rate of recycled brick aggregate increased, the

compressive strength and splitting tensile strength of recycled brick aggregate concrete gradually decreased.

- 2) Compared with recycled brick aggregate concrete without waste fiber, the compression failure mode of brick aggregate concrete with waste fiber was more complex, including aggregate fracture failure and aggregate cataclastic failure.
- 3) The incorporation of waste fiber could improve the mechanical properties of recycled brick aggregate concrete. However, the content should be within a reasonable range; otherwise, it would have a negative impact on mechanical properties.
- 4) The splitting tensile strength of recycled brick aggregate concrete mainly depended on the amount of brick aggregate at the stressed zone; the waste fiber transferred the load at the stressed zone to the surrounding and improved the concrete splitting tensile strength.
- 5) Through microstructural analysis, the mechanisms by which recycled brick aggregate deteriorated the mechanical properties of concrete and waste fiber improved the mechanical properties of recycled brick aggregate concrete were revealed.

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