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Research on the Uniaxial Compression Performance of Basalt Fiber-reinforced Recycled Aggregate Concrete

Shu SUN [1], Hsingwei TAI [2, 3], Zhenyu TAN [4], Chiachen WEI [5] *

[1] *School of Urban and Rural Construction, Taizhou Polytechnic College, Taizhou, Jiangsu 225300, China*
[2] *Higher-educational Engineering Research Centre for Intelligence and Automation in Construction of Fujian Province College of Civil Engineering, Huaqiao University, Xiamen, 361021, China*
[3] *Department of Engineering and Management, International College Krirk University, Bangkok, 10220, Thailand*
[4] *Faculty of Engineering, University of Malaya, Kuala Lumpur, 50603, Malaysia*
[5] *Department of Civil Engineering, Pingtung University of Science and Technology, Pingtung 912301, Taiwan*

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This study improves the mechanical properties of recycled coarse aggregate concrete (RAC) by adding basalt fibers, thereby promoting the widespread application of recycled concrete in engineering. The research results indicate that basalt fibers can increase the cube compressive strength of recycled concrete, the optimal dosage of basalt fibers is 0.3 %, and an increase in compressive strength can increase the compressive strength by 7.96 %. The presence of basalt fibers can form a three-dimensional disordered distribution support system inside recycled concrete, limiting the generation and propagation of microcracks under uniaxial compression, maintaining a certain degree of integrity during the failure process of recycled concrete, and making the descending section of the stress–strain curve relatively stable. With increasing basalt fiber content, the peak stress of recycled concrete under uniaxial compression tends to first increase but then decrease, whereas the peak strain of recycled concrete under uniaxial compression tends to increase. A calculation model for the compressive strength, peak stress, and peak strain of basalt fiber–reinforced recycled concrete is constructed. The strengthening mechanism of basalt fibers on the uniaxial compression performance of recycled concrete is discussed.

Keywords: uniaxial compression performance, basalt fiber, compressive strength, recycled aggregate concrete.

1. INTRODUCTION

Basalt fiber-reinforced recycled concrete is an innovative material that breaks through the performance bottleneck of traditional concrete [1, 2]. Concrete is limited in engineering applications because of its low tensile and flexural strengths, high brittleness, and other defects, whereas fiber-reinforced technology can significantly improve its performance by increasing toughness and preventing cracking [3, 4]. Basalt fibers, as high-performance fibers, combine corrosion resistance, impact resistance, and good chemical compatibility with cement-based materials. It can effectively bridge cracks, transmit stress, and improve the toughness of concrete. Basalt fiber-reinforced recycled concrete incorporates basalt fibers into the recycled concrete system, forming a three-dimensional reinforcement network through the fiber matrix interface effect. This not only suppresses crack propagation caused by defects in recycled aggregates but also compensates for their strength loss. In addition, the bridging effect of fibers on microcracks significantly enhances the crack resistance and durability of composite materials [6, 7].

Studying the damage characteristics of RAC materials under uniaxial compression can provide a basis for damage mechanism analysis and constitutive model establishment. Folino et al. [8] focused on the mechanical behavior of recycled coarse aggregate concrete under uniaxial compression and proposed a failure criterion on the basis of performance parameters. Experiments have shown that as the replacement rate of recycled aggregates increases, the compressive strength and elastic modulus of RAC decrease. The model can effectively predict the peak strength of recycled coarse aggregate concrete by adjusting the performance parameters, verifying its applicability to recycled concrete. Guo et al. [9] revealed the failure mechanism of recycled concrete under uniaxial compression through digital image correlation technology and microscopic testing and established a correlation between microscopic parameters and macroscopic properties through strain evolution analysis. Liu et al. [10] studied the uniaxial compression constitutive relationship of recycled concrete with C25 (Compressive strength is 25 MPa) and C35 strength grades under different replacement rates (0 % ~ 100 %). Experiments have shown that an increase in the replacement ratio leads to a decrease of approximately 15 % in peak stress, a decrease in the elastic modulus, and an increase in fluctuations in the peak strain and ultimate strain. In addition, a modified damage constitutive model was proposed, and it was found that the parameters of the descending segment did not monotonically change with the replacement rate. Stress−strain curve calculation software was developed.

Basalt fiber content significantly affects the mechanical properties of concrete, and there is a nonlinear relationship between the fiber content and compressive strength that first increases but then decreases [11]. After exceeding the

* Corresponding author: C. Wei
E-mail: *arnold@mail.npust.edu.tw*

critical content, the strength deteriorates due to the fiber agglomeration effect. The improvement in flexural strength is most significant, with an increase of 42 % when the dosage is 0.4 % [12]. However, after exceeding the threshold dosage, the enhancement effect shows a nonlinear decline with age [13]. Zheng et al. [14] confirmed that the basalt fiber content is a key parameter affecting the mechanical properties of recycled concrete systems and reported that 0.2 % is the optimal content. Ahmed et al. [15] reported that blending treated recycled aggregates with basalt fibers can significantly increase the splitting tensile and bending strengths of recycled concrete. With respect to the fiber morphology parameters, Zheng et al. [16] reported that the effect of the basalt fiber length on the cube compressive strength is limited, but increasing the fiber length can effectively improve the splitting tensile and bending strengths. The current research consensus indicates that basalt fibers suppress crack propagation through the fiber bridging effect, thereby increasing the strength of concrete. However, there are still differences in their impact on mechanical properties: most studies have shown that basalt fibers can significantly improve the toughness, flexural strength, and deformation capacity of concrete [17 – 21], but some studies have reported negative effects on its mechanical properties [22, 23].

The uniaxial compression constitutive relationship, as a macroscopic mechanical index characterizing the uniaxial compression performance of basalt fiber-reinforced recycled concrete, is the theoretical basis for the ultimate bearing capacity calculation and nonlinear finite element analysis. Different scholars have proposed various theoretical frameworks on the basis of differences in material composition. Guo et al. [24] established a modified stress–strain constitutive equation by analyzing the coupling effect of the basalt fiber volume fraction and aspect ratio on C40 recycled aggregate concrete. Chen et al. [25] constructed an adaptive stress–strain constitutive relationship for C30 basalt fiber rubber recycled concrete on the basis of the model framework of the Chinese national standard GB50010-2010 [26]. Zhao et al. [27] quantified the evolution of the constitutive parameters of C40-grade basalt fiber-reinforced recycled concrete under uniaxial compression tests, considering the effect of the fiber content on the characteristic segments of the curve. Yu et al. [28] proposed a compression constitutive model for basalt fiber-reinforced recycled concrete with clear physical significance through quasistatic experiments combined with damage mechanics theory.

This paper comprehensively analyzes the influence of basalt fibers on the compressive strength and uniaxial compression performance of recycled concrete cubes and establishes a calculation model for the compressive strength, peak uniaxial compression stress, and peak uniaxial compression strain of basalt fiber-reinforced recycled concrete cubes. This study provides a calculation basis for the application of basalt fiber-reinforced recycled concrete in construction.

2. EXPERIMENTAL DETAILS

2.1. Materials

The raw material selection is as follows: the cement is P.O 42.5 ordinary Portland cement, and its properties are shown in Table 1 (GB175-2007 [29]); natural river sand is selected as the fine aggregate, and its properties are shown in Table 2 (JGJ52-2006 [30]); recycled coarse aggregate is crushed from abandoned concrete at a construction site in Taizhou city, and its properties are shown in Table 3; and the water reducing agent is a highly efficient polycarboxylate water reducing agent with a water reduction efficiency of 25 % to 35 %. Basalt fibers are added at 5 different volume ratios of 0 %, 0.1 %, 0.2 %, 0.3 %, and 0.4 %. The properties of the basalt fibers are shown in Table 4.

Table 1. Properties of the cement

Fineness, m^2/kg	Initial setting time, min	Final setting time, min	28-day compressive strength, MPa	28-day flexural strength, MPa
345	168	340	45.5	7.4

Table 2. Properties of the fine aggregates

Apparent density, kg/m^3	Mud content, %	Fineness modulus
2850	2.1	2.4

Table 3. Properties of recycled coarse aggregate

Particle size distribution, mm	Apparent density, kg/m^3	Crushing index, %	Water absorption, %
5 – 40	2.53	15.4	12.4

Table 4. Properties of basalt fibers

Diameter, um	Density, g/cm^3	Elastic modulus, GPa	Length, mm	Tensile strength, MPa
11	2.63	95	6	2800

2.2. Mix proportions of recycled concrete

In this study, the target strength of recycled concrete is 30 MPa. In accordance with the design standard for the recycled concrete mix proportion (T/CECS 1293-2023 [31]), the mix proportion of recycled concrete was designed, and the mix proportion was adjusted on the basis of the concrete adaptation results. The final mix proportions were determined as shown in Table 5.

Table 5. Mix proportion

Type	Cement, kg/m^3	Water, kg/m^3	Sand, kg/m^3	Recycled aggregate, kg/m^3	Basalt fiber length, mm	Basalt fiber content, %	Water reducing agent, kg/m^3
RC-0-0	360	180	720	1150	-	0	3.6
RC-0.1-6	360	180	720	1150	6	0.1	3.6
RC-0.2-6	360	180	720	1150	6	0.2	3.6
RC-0.3-6	360	180	720	1150	6	0.3	3.6
RC-0.4-6	360	180	720	1150	6	0.4	3.6

2.3. Sample production and testing

Cubic samples with dimensions of 100 mm × 100 mm × 100 mm were produced to test the compressive strength of basalt fiber-reinforced recycled concrete, and prism samples with dimensions of 100 mm × 100 mm × 00 mm were produced to test the uniaxial compression performance of basalt fiber-reinforced recycled concrete.

The production process of basalt fiber-reinforced recycled concrete samples is as follows:

1) place the cement and aggregate into the mixer and dry them for a period of time to ensure that the cement and aggregate are fully mixed evenly. The dry mixing time was 120 s; 2) basalt fibers were sprinkled into the mixer, and stirring was continued to fully disperse the fibers in the aggregate. Owing to the flexibility and length of basalt fibers, agglomeration may occur. Therefore, it is necessary to extend the mixing time appropriately, usually 180 – 300 s, to ensure that the fibers are evenly dispersed in the concrete; 3) an appropriate amount of water and water reducing agent should be added for wet mixing. The wet mixing time was 180 s to achieve the designed workability of the concrete; 4) pour the concrete into the corresponding mold and vibrate it on the vibration table for 120 s to ensure uniformity inside the concrete sample; 5) After standing in the concrete mold for 24 h, the sample was demolded and placed in a standard concrete curing box for 28 days of curing.

The compression test and uniaxial compression test are both completed via a hydraulic servo universal testing machine (GB/T 50081-2019 [32]). During uniaxial compression testing, vertical strain gauges are placed vertically on both sides, and a displacement gauge is fixed on each side of the sample, as shown in Fig. 1.

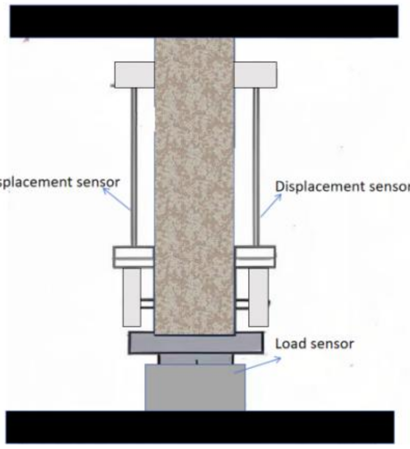

Fig. 1. Uniaxial compression test device

The sample was placed at the center of the lower pressure plate of the pressure testing machine so that the pressure-bearing surface of the sample was perpendicular to the top surface during molding. Steel pads were placed between the sample and the upper and lower pressure plates to ensure a uniform stress distribution on the sample. When a sample approaches failure, attention should be given to the development of cracks in the sample until it fails, and the failure load should be recorded. The loading rate for compressive testing was 0.3 MPa/s, whereas the loading rate for uniaxial compression testing was 0.02 mm/min.

3 RESULTS AND DISCUSSION

3.1. Cubic compressive strength

The variation trend of the cubic compressive strength of basalt fiber-reinforced recycled concrete is shown in Fig. 2. Fig. 2 shows that the addition of basalt fibers can increase the cubic compressive strength of recycled concrete, which is consistent with the results obtained by Wang [33]. When the dosage was 0.1 %, 0.2 %, 0.3 %, and 0.4 %, the cube compressive strength of recycled concrete without basalt fibers increased by 7.01 %, 11.96 %, 12.41 %, and 6.57 %, respectively.

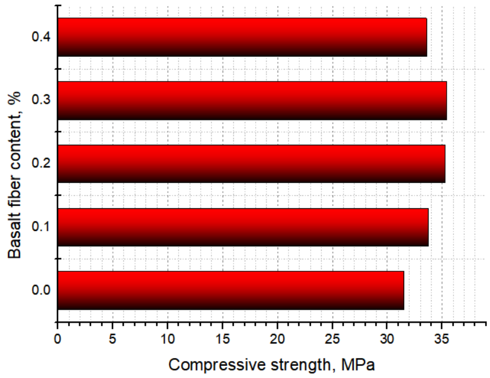

Fig. 2. Compressive strength of basalt fiber-reinforced recycled concrete

The reasons for this are as follows: 1) basalt fibers have high tensile strength and good flexibility. In recycled concrete, fibers can withstand a certain amount of tensile stress. When the concrete matrix is subjected to external forces and produces small cracks, fibers can cross the cracks and prevent further expansion, thereby increasing the toughness of the concrete and improving its ability to resist damage; 2) some pores and microcracks inside recycled concrete easily expand and connect under pressure, leading to concrete failure. The addition of basalt fibers can form a three-dimensional random distribution network inside the concrete, hindering the expansion and connection of microcracks [33] and allowing the concrete to withstand greater pressure before failure, thereby improving its compressive strength; 3) basalt fibers are evenly distributed in recycled concrete, which can evenly transfer the load acting on the concrete to the entire structure, avoid local stress concentration, and thus improve the compressive strength of the concrete. Moreover, the presence of fibers can also improve the stress state inside concrete, increasing its material properties under compression.

In addition, when the basalt fiber content reached 0.4 %, the improvement effect on the compressive strength of the recycled concrete decreased, indicating that the basalt fiber content should be controlled within a reasonable range. This is consistent with the results obtained from Wang's research on the mechanical properties of polypropylene fiber-reinforced concrete [34]. The reasons for this situation are as follows [35]: 1) when the amount of basalt fiber added is too large, it is difficult to disperse evenly in the concrete mixture, and fiber aggregation is prone to occur. Agglomerated fibers not only fail to exert their reinforcing effect but also form weak areas inside the concrete, becoming stress concentration points, which make the concrete prone to failure from these areas when subjected to stress, thereby reducing the compressive strength of the concrete; 2) although basalt fibers can form good interfacial bonds with the cement matrix, excessive fibers can increase the area of the interfacial transition zone. The interface transition zone itself is a weak link in concrete structures, and an increase in area means an increase in weak areas. Moreover, excessive fibers may affect the normal hydration and hardening process of the cement slurry, making the structure of the interface transition zone insufficiently dense, reducing the interfacial bonding strength, and thus affecting the overall compressive performance of the concrete; 3) excessive addition of basalt fibers may alter the workability of concrete mixtures, such as reducing their flowability. To ensure construction performance, it may be necessary to increase the amount of water or admixtures used, which can cause changes in the water–cement ratio of the concrete, thereby affecting the strength of the cement stone and the compactness of the matrix. In addition, excessive fibers occupy a certain amount of space, which may reduce the number of contact points between the aggregates, destroy the tightly packed structure of the aggregates, affect the skeleton effect inside the concrete, and reduce the compressive strength.

The relationship between the compressive strength of recycled concrete and the basalt fiber content was obtained through data fitting (Fig. 3):

$$F_c = -68r^2 + 33.04r + 31.374 \qquad R^2 = 0.9647, \tag{1}$$

where F_c is the compressive strength of the concrete; r is the replacement ratio of the basalt fibers.

The sum of squared residuals is 0.17752, and the goodness of fit R^2 is 0.96471, indicating that the fitted curve has high accuracy.

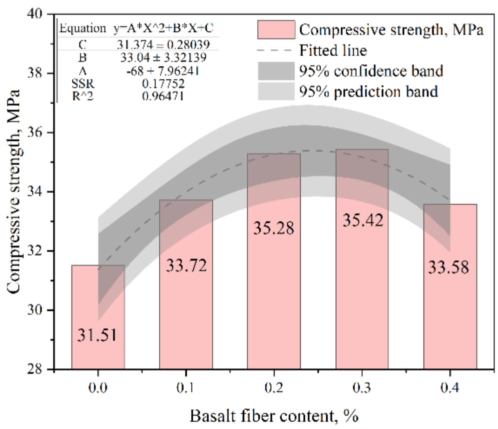

Fig. 3. Relationship between the compressive strength of recycled concrete and the basalt fiber content

3.4. Uniaxial compression failure mode

The uniaxial compression failure mode of basalt fiber recycled concrete is shown in Fig. 4. The failure mode of basalt fiber-reinforced recycled concrete is generally consistent with that of recycled concrete [36]. At the initial stage of loading, the microcracks inside the sample were in a closed or stable state, and the aggregate and cement particles jointly bore the load. There were no obvious visible cracks on the surface of the samples. As the load increased, microcracks began to appear inside the sample when the stress reached a certain proportion of the ultimate stress.

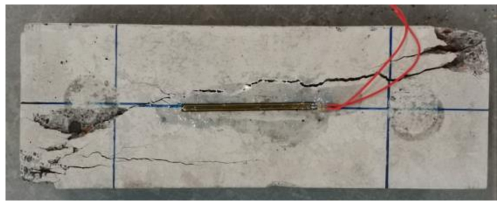

Fig. 4. Uniaxial compression failure mode

These microcracks first occurred in the transition zone between the aggregate and cement stone interfaces, as this area was a weak link inside the concrete, with many pores and defects. As the load further increased, microcracks gradually expanded and extended into the interior of the cement, whereas new microcracks continued to form in the cement. At this point, some small cracks begin to appear on the surface of the sample. When the stress reached the ultimate stress, the sample entered the failure stage. At this point, the cracks rapidly expand and connect, and the width and length of the cracks on the surface of the sample continue to increase, causing some aggregate particles to detach. As the crack further developed, the sample was divided into several small pieces by the crack, and the connections between these small pieces gradually weakened. The bearing capacity of the sample rapidly decreased, and the sample eventually lost its bearing capacity, resulting in complete failure of the sample. The failure mode of recycled concrete samples after destruction usually involves diagonal cracks or intersecting cracks because under uniaxial compression, the internal principal stress direction of the concrete is at a certain angle to the loading direction, causing cracks to develop along the principal stress direction.

3.3. Stress–strain curves

The uniaxial compressive stress–strain curves of each group of recycled concrete samples are shown in Fig. 5.

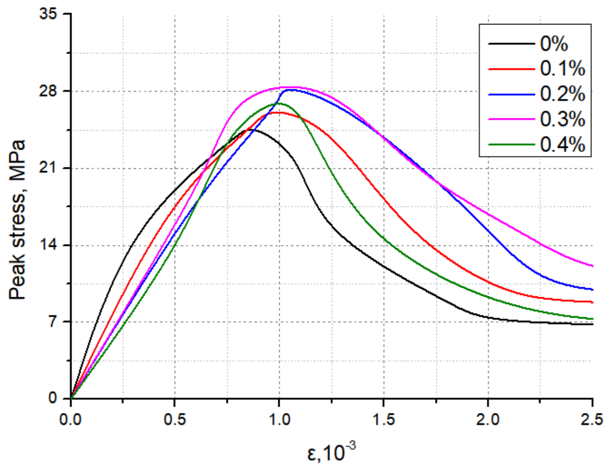

Fig. 5. Uniaxial compressive stress–strain curves

This process can be divided into the following four stages:

1) elastic stage: in uniaxial compression tests, the curve shape of recycled concrete with added basalt fibers in the elastic stage is similar to that of recycled concrete without added basalt fibers, both showing an approximately straight

line shape. However, basalt fibers can form a three-dimensional disordered distribution support system inside recycled concrete, limiting the generation and propagation of microcracks. Therefore, its elastic stage is slightly prolonged compared with that of recycled concrete without basalt fibers;

2) yield stage: there is a certain platform section for recycled concrete without the addition of basalt fibers. When basalt fibers are added, owing to the reinforcement and toughening effects of the fibers, the yield stage of recycled concrete is no longer a typical platform shape;

3) strengthening stage: after entering the strengthening stage, the slope of the stress–strain curve of recycled concrete without basalt fibers gradually decreases until it reaches the peak stress and begins to decrease. The material mixed with basalt fibers can effectively transmit stress and delay the propagation of matrix cracks due to the interfacial bonding between the fibers and the matrix and a significant improvement in the strength of the material.

4) destruction stage: the stress–strain curve of recycled concrete without basalt fibers sharply decreases during the destruction stage, indicating that the material rapidly loses its bearing capacity. The addition of basalt fibers can maintain a certain degree of integrity in recycled concrete during failure, and the stress–strain curve decreases relatively smoothly. This is because fibers can bridge cracks, prevent further crack propagation, and thus give the material good resistance to failure.

3.4. Peak stress under uniaxial compression

The variation trend of the peak uniaxial compression stress of the basalt fiber recycled concrete is shown in Fig. 6. After adding basalt fibers, the peak uniaxial compression stress of the recycled concrete increased, and this phenomenon validates Shen's research findings [36]. When the content of basalt is 0.1 %, 0.2 %, 0.3 %, and 0.4 %, the peak uniaxial compressive stress of recycled concrete with basalt fibers increases by 6.13 %, 14.05 %, 15.41 %, and 7.96 %, respectively. The reasons for this situation are as follows [37]: 1) basalt fibers have high tensile strengths and elastic moduli. When evenly distributed in concrete, they can span microcracks, such as a "bridge", preventing further expansion and connection of cracks and allowing the concrete to withstand greater loads before failure, thereby increasing the peak uniaxial compression stress; 2) the interface transition zone between the aggregate of recycled concrete and the cement matrix is a weak link. The surface of basalt fibers has a certain roughness, which can better bond with the cement matrix. During the concrete mixing process, the dispersion of fibers can make the thickness of the interface transition zone more uniform, increase the density of the structure, and increase the bonding force between the aggregate and the matrix. This enables the concrete to transmit stress more effectively under compression, thereby increasing the peak uniaxial compression stress; 3) the addition of basalt fibers improved the toughness of the concrete matrix. During uniaxial compression, the matrix can better withstand deformation without sudden failure, continuously absorbs energy, delay the development of internal damage in the concrete, and only fail when the stress level of the concrete increases, thereby increasing the peak stress of uniaxial compression; 4) basalt fibers form a three-dimensional network structure inside the concrete, which limits the development of microcracks inside the concrete. When concrete is under pressure, fibers can disperse stress, avoiding stress concentration and rapid expansion of microcracks, allowing the internal structure of the concrete to remain relatively intact under high stress, thereby increasing the peak uniaxial compression stress.

In addition, when the basalt fiber content reached 0.4 %, the improvement effect on the peak uniaxial compression stress of recycled concrete decreased, which was consistent with the experimental results of the compressive strength of recycled concrete. This is because when the amount of basalt fiber added is too high, agglomeration occurs due to difficulty in uniform dispersion, forming stress concentration points. Moreover, excessive fibers can increase the interface transition zone area and loosen its structure, which may also change the workability of concrete and affect the water–cement ratio and aggregate stacking structure. These factors combined reduce its improvement effect on the peak uniaxial compression stress of recycled concrete.

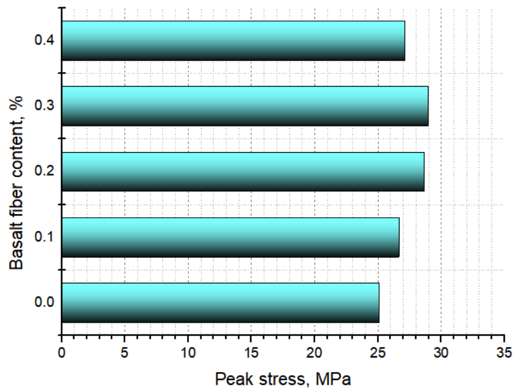

Fig. 6. Peak stress

The relationship between the peak stress of recycled concrete and the basalt fiber content was obtained through data fitting (Fig. 7):

$$F_f = -60.5r^2 + 30.53r + 24.832 \qquad R^2 = 0.8498, \qquad (2)$$

where F_f is the peak stress of the concrete; r is the replacement rate of the basalt fibers.

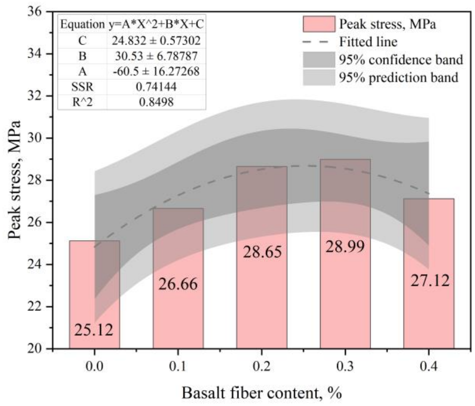

Fig. 7. Relationship between the peak stress and basalt fiber content

The sum of squared residuals is 0.74144, and the goodness of fit R^2 is 0.8498, indicating that the fitted curve has high accuracy.

3.5. Peak strain under uniaxial compression

The peak strain variation trend of basalt fiber recycled concrete under uniaxial compression is shown in Fig. 8. With increasing basalt fiber content, the peak strain of recycled concrete under uniaxial compression tended to increase, which is similar to the experimental results of Guo [38]. When the content of basalt was 0.1 %, 0.2 %, 0.3 %, and 0.4 %, the peak strain of uniaxial compression of recycled concrete with basalt fibers increased by 9.81 %, 16.52 %, 26.45 %, and 27.13 %, respectively. This is mainly due to the good bonding between the basalt fibers and the cement matrix, which can effectively prevent the expansion and connection of microcracks, allowing the concrete to withstand greater deformation and increasing the peak strain before failure. Moreover, the presence of fibers improves the toughness of concrete, enabling it to adapt better to deformation during compression, further promoting an increase in peak strain.

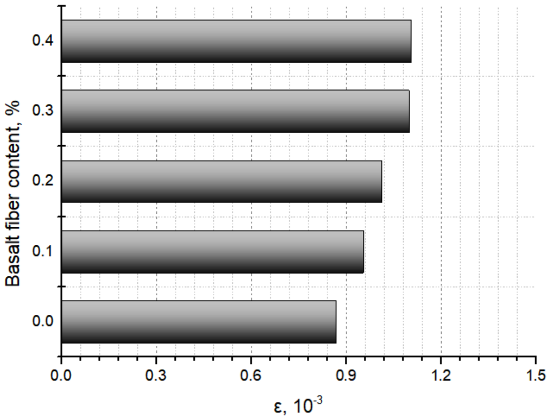

Fig. 8. Peak strain

The relationship between the peak stress of recycled concrete and the basalt fiber content was obtained through data fitting (Fig. 9):

$$S_f = 0.9755r - 5.7619 \qquad R^2 = 0.9697, \tag{3}$$

where S_f is the peak stress of the concrete; r is the replacement ratio of basalt fibers.

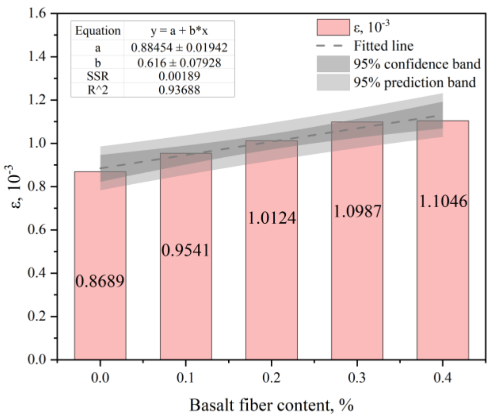

Fig. 9. Relationship between the peak strain of recycled concrete and the basalt fiber content

The sum of squared residuals is 0.00189, and the goodness of fit R^2 is 0.93688, indicating that the fitted curve has high accuracy.

3.6. Comparison of the uniaxial compressive strengths of different types of fiber-reinforced concrete

The experimental results (BR) of this paper are compared with those of Gao [38], Zhang [39], and Feng [40], as shown in Fig. 10. Among them, Gao [38] represented the uniaxial compressive strength of basalt fiber-reinforced ordinary concrete (BO), Zhang [39] represented the uniaxial compressive strength of carbon fiber-reinforced recycled concrete (CR), and Feng [40] represented the uniaxial compressive strength of steel fiber and plastic steel hybrid fiber-reinforced recycled concrete (SF+PSF R). Through comparison, it was found that the improvement effect of basalt fiber on the uniaxial compressive strength of recycled concrete is greater than its improvement effect on the uniaxial compressive strength of ordinary concrete, which is 10.3 % greater. The main reason for this phenomenon is that in ordinary concrete, basalt fibers only strengthen the cement mortar. In recycled concrete, basalt fibers not only strengthen the cement mortar but also enhance the interface transition zone between the adhesive mortar on the surface of the recycled coarse aggregate and the new mortar.

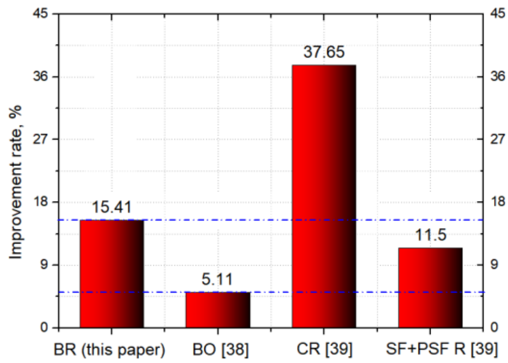

Fig. 10. Comparison of the uniaxial compressive strengths of different types of fiber-reinforced concrete

In addition, the improvement effect of carbon fibers on the uniaxial compressive strength of recycled concrete is greater than that of basalt fibers on the uniaxial compressive strength of recycled concrete. The reasons for this situation are as follows: 1) the elastic modulus of carbon fibers is significantly greater than that of basalt fibers. During the compression process of concrete, high modulus fibers can more effectively share the load, suppress crack propagation, and thus delay the failure of the concrete; 2) the tensile strength of the carbon fibers is also greater than that of the basalt fibers, and their stronger tensile ability can bridge cracks more efficiently and reduce the stress concentration; 3) uniaxial compression failure is caused mainly by the lateral expansion of the concrete (Poisson effect). The high modulus of carbon fibers can significantly suppress lateral deformation, whereas basalt fibers have a weaker restraining effect because of their lower modulus.

The improvement effect of steel fibers and plastic steel hybrid fibers on the uniaxial compressive strength of recycled concrete is lower than that of basalt fibers on the uniaxial compressive strength of recycled concrete. The reasons for this situation are as follows: 1) the elastic modulus of steel fibers is significantly greater than that of the recycled concrete matrix, which may lead to stress transmission incompatibility during compression due to the large difference in modulus. Steel fibers bear excessive loads too early, causing local stress concentration and weakening the overall integrity of the matrix; 2) the modulus of plastic steel fibers is too low, making it difficult to effectively constrain the lateral expansion of concrete under compression. In hybrid fiber systems, low modulus fibers may become weak links, offsetting the reinforcing effect of steel fibers; 3) steel fibers have a smooth surface and poor chemical compatibility with the cement matrix, making them prone to interface slip under stress and weakening the bridging effect; 4) when steel fibers (high modulus) are mixed with plastic steel fibers (low modulus), the low modulus fibers undergo significant deformation in the early stages of compression, whereas the high modulus fibers do not fully exert their function, leading to synergistic effect fracture. The two cannot form a continuous stress transmission path.

4. ENHANCEMENT MECHANISM ANALYSIS

The mechanism of the uniaxial compression performance of basalt fiber-reinforced recycled coarse aggregate concrete is shown in Fig. 11. In the undamaged state (Fig. 11 a), basalt fibers exhibit a three-dimensional random distribution in the concrete matrix. In the initial cracking stage (Fig. 11 b), microcracks appear in the concrete matrix. When microcracks begin to propagate in the transition zone of the recycled aggregate interface or inside the matrix, fibers cross both sides of the crack through the "bridging effect", suppressing the expansion of the crack width and changing its propagation path, forming a "multilevel crack resistance" mechanism. In the crack propagation stage (Fig. 11 c), the crack path becomes tortuous due to the presence of fibers, resulting in multiple branching cracks. In the final stage of failure (Fig. 11 d), the fibers are pulled out or broken, but the macroscopic integrity of the sample is still maintained.

Notably, when the fiber network forms a "secondary load-bearing system", when stress concentration occurs in local areas due to recycled aggregate defects, and the fibers achieve load redistribution through stress transmission, delaying the formation of main cracks (Fig. 11 e). In addition, during uniaxial compression, basalt fibers can consume a large amount of energy. When microcracks appear and propagate inside concrete, the processes of fiber tension, fracture, and friction slip with the matrix absorb energy, thereby delaying the failure process of the concrete and improving its compressive toughness (Fig. 11 f).

5. CONCLUSIONS

1. Basalt fibers could increase the cubic compressive strength and uniaxial compression peak stress of recycled concrete, as the presence of basalt fibers could form a three-dimensional disordered distribution support system inside recycled concrete, limiting the generation and propagation of microcracks.

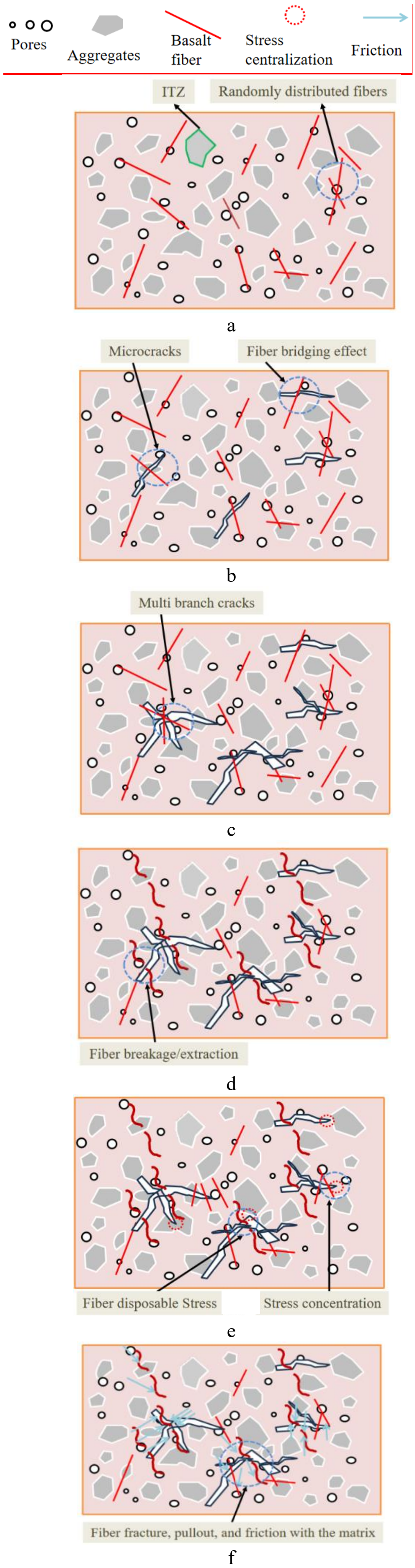

Fig. 11. Schematic diagram of basalt fiber reinforcement

2. With increasing basalt fiber content, the cubic compressive strength and uniaxial compression peak stress first tended to increase but then tended to decrease, whereas the uniaxial compression peak strain of recycled concrete under uniaxial compression tended to increase.
3. The calculation model for compressive strength, peak stress, and peak strain of basalt fiber-reinforced recycled concrete was constructed.
4. The improvement effect of basalt fibers on the uniaxial compressive strength of recycled concrete was greater than its improvement effect on ordinary concrete. The improvement effect of basalt fibers on the uniaxial compressive strength was greater than that of steel fibers and plastic steel hybrid fibers but lower than that of carbon fibers.
5. Basalt fibers suppressed the propagation of crack width and changed its propagation path through the "bridging effect", forming a "multilevel crack resistance" mechanism. When the basalt fibers were pulled out or broken, the macroscopic integrity of the concrete sample was still maintained.

This study demonstrates the feasibility of using basalt fibers to increase the performance of recycled concrete, solving the problem of low engineering utilization caused by the poor mechanical properties of recycled concrete. This approach can promote the widespread application of recycled concrete in engineering and promote the low-carbon and sustainable development of the construction industry. In addition, the study of the uniaxial compression performance of basalt fiber-reinforced recycled concrete can quantify the mechanical response of the material throughout the entire process from elastic deformation to plastic yield and failure, providing a core theoretical basis for engineering structure design, numerical simulation, safety assessment, and material optimization.

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REFERENCES

1. **Xu, W., Tan, C., Xu, W., Zhang, T., Xiong, B., Wang, S., Du, D.** Mechanical Properties and Constitutive Relation of Recycled Aggregate Concrete Reinforced with Face Mask Fibre and Basalt Fibre under Uniaxial Cyclic Compression *Structures* 69 2024: pp. 107364. https://doi.org/10.1016/j.istruc.2024.107364
2. **Zhang, C., Wang, Y., Zhang, X., Ding, Y., Xu, P.** Mechanical Properties and Microstructure of Basalt Fiber-Reinforced Recycled Concrete *Journal of Cleaner Production* 278 2021: pp. 123252. https://doi.org/10.1016/j.jclepro.2020.123252
3. **Cuenca, E., Postolachi, V., Ferrara, L.** Cellulose Nanofibers to Improve the Mechanical and Durability Performance of Self-Healing Ultra-High Performance Concretes Exposed to Aggressive Waters *Construction and Building Materials* 374 2023: pp. 130785. https://doi.org/10.1016/j.conbuildmat.2023.130785
4. **Wang, J., Li, Y., Qiu, Z., Zhang, Y.** Experimental Research on Compressive Properties of Recycling Polypropylene (PP) Fiber Recycled Coarse Aggregate Concrete *Journal of Building Engineering* 76 2023: pp. 107403. https://doi.org/10.1016/j.jobe.2023.107403
5. **Yuan, C.F., Li, S.** Research Review on Fiber Reinforced Recycled Aggregate Concrete *Concrete* 9 2018: pp. 31-34+39. (in Chinese) https://doi.org/10.3969/j.issn.1002-3550.2018.09.007
6. **Ahmed, W., Lim, C.W.** Multicriteria Performance Assessment of Sustainable Recycled Concrete Produced via Hybrid Usage of Basalt, Polypropylene and Glass Fiber *Construction and Building Materials* 397 2023: pp. 132462. https://doi.org/10.1016/j.conbuildmat.2023.132462
7. **Liang, N., Geng, S., Mao, J., Liu, X., Zhou, X.** Investigation on Cracking Resistance Mechanism of Basalt-Polypropylene Fiber Reinforced Concrete Based on SEM Test *Construction and Building Materials* 411 2024: pp. 134102. https://doi.org/10.1016/j.conbuildmat.2023.134102
8. **Folino, P., Xargay, H.** Recycled Aggregate Concrete—Mechanical Behavior under Uniaxial and Triaxial Compression *Construction and Building Materials* 56 2014: pp. 21 – 31. https://doi.org/10.1016/j.conbuildmat.2014.01.073
9. **Guo, J., Gao, S., Liu, A., Wang, H., Guo, X., Xing, F., Zhang, H., Qin, Z., Ji, Y.** Experimental Study on Failure Mechanism of Recycled Coarse Aggregate Concrete under Uniaxial Compression *Journal of Building Engineering* 63 2023: pp. 105548. https://doi.org/10.1016/j.jobe.2022.105548
10. **Liu, B., Zhang, B., Wang, Z.Z., Bai, G.L.** Study on the Stress–Strain Full Curve of Recycled Coarse Aggregate Concrete under Uniaxial Compression *Construction and Building Materials* 363 2023: pp. 129884. https://doi.org/10.1016/j.conbuildmat.2022.129884
11. **Sun, X., Gao, Z., Cao, P., Zhou, C.** Mechanical Properties Tests and Multiscale Numerical Simulations for Basalt Fiber Reinforced Concrete *Construction and Building Materials* 202 2019: pp. 58 – 72. https://doi.org/10.1016/j.conbuildmat.2019.01.018
12. **Zhou, H., Jia, B., Huang, H., Mou, Y.** Experimental Study on Basic Mechanical Properties of Basalt Fiber Reinforced Concrete *Materials* 13 (6) 2020: pp. 1362. https://doi.org/10.3390/ma13061362
13. **Jiang, C., Fan, K., Wu, F., Chen, D.** Experimental Study on the Mechanical Properties and Microstructure of Chopped Basalt Fibre Reinforced Concrete *Materials & Design* 58 2014: pp. 187 – 193. https://doi.org/10.1016/j.matdes.2014.01.056
14. **Zheng, Y., Zhuo, J., Zhang, Y., Zhang, P.** Mechanical Properties and Microstructure of Nano-SiO_2 and Basalt-Fiber-Reinforced Recycled Aggregate Concrete *Nanotechnology Reviews* 11 (1) 2022: pp. 2169 – 2189. https://doi.org/10.1515/ntrev-2022-0134
15. **Ahmed, W., Lim, C.W.** Coupling Effect Assessment of Vacuum Based Pozzolana Slurry Encrusted Recycled Aggregate and Basalt Fiber on Mechanical Performance of Fiber Reinforced Concrete *Construction and Building Materials* 300 2021: pp. 124032. https://doi.org/10.1016/j.conbuildmat.2021.124032
16. **Zheng, Y., Zhuo, J., Zhang, P., Ma, M.** Mechanical Properties and Meso-Microscopic Mechanism of Basalt Fiber-Reinforced Recycled Aggregate Concrete *Journal of Cleaner Production* 370 2022: pp. 133555. https://doi.org/10.1016/j.jclepro.2022.133555
17. **Di Ludovico, M., Prota, A., Manfredi, G.** Structural Upgrade Using Basalt Fibers for Concrete Confinement

Journal of Composites for Construction 14 (5) 2010: pp. 541 – 552. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000114

18. **Sim, J., Park, C.** Characteristics of Basalt Fiber as a Strengthening Material for Concrete Structures *Composites Part B: Engineering* 36 (6 – 7) 2005: pp. 504 – 512. https://doi.org/10.1016/j.compositesb.2005.02.002
19. **Dias, D.P., Thaumaturgo, C.** Fracture Toughness of Geopolymeric Concretes Reinforced with Basalt Fibers *Cement and Concrete Composites* 27 (1) 2005: pp. 49 – 54. https://doi.org/10.1016/j.cemconcomp.2004.07.001
20. **Li, W., Xu, J.** Mechanical Properties of Basalt Fiber Reinforced Geopolymeric Concrete under Impact Loading *Materials Science and Engineering: A* 505 (1 – 2) 2009: pp. 178 – 186. https://doi.org/10.1016/j.msea.2008.11.063
21. **Hillerborg, A.** The Theoretical Basis of a Method to Determine the Fracture Energy GF of Concrete *Materials and Structures* 18 1985: pp. 291 – 296. https://doi.org/10.1007/BF02472919
22. **Recommendation, R.D.** Determination of the Fracture Energy of Mortar and Concrete by Means of Three-Point Bend Tests on Notched Beams *Materials and Structures* 18 (106) 1985: pp. 285 – 290. https://doi.org/10.1007/BF02472918
23. **Peterson, P.E.** Fracture Energy of Concrete: Method of Determination *Cement and Concrete Research* 10 (1) 1980: pp. 79 – 89. https://doi.org/10.1016/0008-8846(80)90054-X
24. **Guo, Y., Liu, Y., Wang, W., Wang, K., Zhang, Y., Hou, J.** Effect of Basalt Fiber on Uniaxial Compression-Related Constitutive Relation and Compressive Toughness of Recycled Aggregate Concrete *Materials* 16 (5) 2023: pp. 1849. https://doi.org/10.3390/ma16051849
25. **Chen, A., Han, X., Chen, M., Wang, X., Wang, Z., Guo, T.** Mechanical and Stress-Strain Behavior of Basalt Fiber Reinforced Rubberized Recycled Coarse Aggregate Concrete *Construction and Building Materials* 260 2020: pp. 119888. https://doi.org/10.1016/j.conbuildmat.2020.119888
26. **GB50010-2010.** Design standards for concrete structures, 2010. (in Chinese)
27. **Zhao, G., Zhao, Z., Chen, Y., Zhang, G.** Experiments on Complete Stress-Strain Curves of Basalt Fiber Reinforced Concrete *Journal of Water Resources and Architectural Engineering* 17 (1) 2019: pp. 103 – 107. (in Chinese) https://doi.org/10.3969/j.issn.1672-1144.2019.01.018
28. **Yu, Y., Wu, R., Cheng, Y., Xu, P.** Uniaxial Compression **Constitutive** Model of Basalt Fiber Resin Concrete *Concrete* 3 2016: pp. 69 – 71. (in Chinese) https://doi.org/10.3969/j.issn.1002-3550.2016.09.017
29. **GB175-2007**. Common Portland Cement, 2007. (in Chinese)
30. **JGJ52-2006**. Standard for Technical Requirements and Test Method of Sand and Crushed Stone (or Gravel) for Ordinary Concrete, 2006. (in Chinese)
31. **T/CECS 1293-2023.** Standard for Mix Proportion Design of Recycled Concrete, 2023.(in Chinese)
32. **GB/T 50081-2019**. Standard for Test Methods of Concrete Physical and Mechanical Properties. 2019. (in Chinese)
33. **Wang, T., Cui, S.A., Ren, X.Y., Zhang, W.S., Yang, X.C., Gong, S.W., Yang, D.Q., Li, B.X., Zhang, W.G., Su, T., Mei, X.F., Duan, L.C., Ma, Z.Y., Cao, X.Y., Yu, X.Y.** Study on The Mechanical Properties and Microstructure of Recycled Brick Aggregate Concrete with Waste Fiber *Reviews on Advanced Materials Science* 63 (1) 2024: pp. 20230175. https://doi.org/10.1515/rams-2023-0175
34. **Cui, S.A., Wang, T., Zhang, Z.C., Sun, X., Li, J.H., Zhang, W.S., Li, B.X., Su, T., Fubo Cao, F.B.** Frost Resistance And Life Prediction Of Recycled Brick Aggregate Concrete With Waste Fiber *Reviews on Advanced Materials Science* 62 (1) 2023: pp. 20230154. https://doi.org/10.1515/rams-2023-0154
35. **Gao, S., Shang, Y.J., Zhou, Y.** Static Characteristics and Fracture Mechanism of Basalt Fiber Reinforced Concrete *Concrete* 11 2024: pp. 93 – 99. (in Chinese) https://10.3969/j.issn.1002-3550.2024.11.017
36. **Shen, D.J., Shi, X., Yong, J., Yin, F.F.** Strain Rate Effect On Bond Stress–Slip Relationship Between Basalt Fiber-Reinforced Polymer Sheet and Concrete *Journal of Reinforced Plastics and Composites* 34 (7) 2015: pp. 547 – 563. https://doi.org/10.1177/0731684415574539
37. **Guo, S.L., Chen, W.S, Lu, Q., Li, G.D.** Experimental Study on Uniaxial Compression of Basalt Fiber Reinforced Recycled Concrete *Journal of Tianjin Chengjian University* 29 (6) 2023: pp. 385 – 390. https://doi.org/10.19479/j.2095-719x.2306385
38. **Gao, S., Shang, Y.J., Zhou, Y.** Static Characteristics and Fracture Mechanism of Basalt Fiber Reinforced Concrete *Concrete* 11 2024: pp. 93 – 99. (in Chinese) https://doi.org/10.16090/j.cnki.hcxw.2023.02.004
39. **Zhang, Z.** Study on Mechanical Properties and Damage Mechanismm of Carbon Fiber Reinforced Recycled Aggregate Concrete. North China University of Water Resources and Electric Power. Master's thesis. 2022. (in Chinese) https://doi.org/10.27144/d.cnki.ghbsc.2022.000437
40. **Feng, J.J.** Study on Compressive Properties of Steel and Macro-polypropylene Hybrid Fibers Reinforced Recycled Coarse Aggregate Concrete. Chang'an University. Master's thesis. 2022. (in Chinese) https://doi.org/10.26976/d.cnki.gchau.2022.000177