Numerical simulation of mechanical properties of recycled concrete based on characterization of interfacial transition zone characteristics

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Abstract. Recycled concrete is the recycling of concrete waste materials. Making full use of recycled concrete can effectively reduce the consumption of natural energy and protect the environment. The interface transition zone of recycled concrete is complex and changeable, which leads to the instability of mechanical properties of recycled concrete. This paper summarizes the numerical simulation of recycled concrete and its interface transition zone, analyses the existing problems, and prospects the future development trend.

Keywords: recycled concrete, interfacial transition zone, mechanical properties, numerical simulation.

1. Introduction
With the rapid development of China's economy, the construction industry is also booming. With the increasing demand for natural resources, concrete waste materials cannot be better reused. Recycled concrete is a new concrete made by crushing, cleaning and grading the discarded concrete blocks, mixing them with grading according to a certain proportion, partially or completely replacing natural aggregates such as sand and stone, and then adding cement and water. Recycled concrete as a green building material, compared with ordinary concrete, it has the disadvantages of large porosity and low durability, resulting in its utilization rate is not very high [1]. Therefore, improving the use efficiency of recycled concrete is an important and priority for governments all over the world. Building energy saving cannot only reduce greenhouse gas emissions and energy shortage, but also make economic development more sustainable [2].

The interface transition zone is the interface between aggregate and cement paste in concrete. Concrete containing recycled aggregate has more interfacial transition zone than conventional concrete, which can be divided into new interfacial transition zone and old interfacial transition zone. This is due to the existence of different composition materials in recycled aggregate [3]. The interfacial transition zone is the area where cracks occur and develop in recycled concrete, and it is also the weakest position in recycled concrete. At present, the research of recycled concrete is mainly based on experiments, and a few studies use simulation methods. This paper summarizes the research on recycled concrete and interface transition zone by using simulation method, summarizes the existing problems, and looks forward to the future research direction of recycled concrete.
2. Numerical simulation of mechanical properties of recycled concrete

Mechanical properties are the most important properties of concrete as building materials. Because we make recycled concrete from waste concrete, some properties of recycled concrete are bound to be different from normal concrete. Dong Teng et al. [5] conducted numerical simulation on the flexural failure of basalt fiber recycled aggregate concrete through experiments and ANSYS software, and concluded that in the flexural failure, the different amount of fiber has little effect on the generation and development of cracks in recycled concrete. Yao Dali et al. [6] analyzed the influence of concrete strength and concrete type on the flexural ductility of recycled concrete beams by using ABAQUS software. The results show that the flexural ductility of recycled concrete beams increases with the increase of concrete strength. Under the same conditions, the flexural ductility of recycled concrete beams is about 17.7% higher than that of ordinary concrete beams. Zhou Jinghai et al. [7] used ANSYS finite element software to simulate the compressive test of recycled concrete, and analyzed their influence on the compressive strength by changing different parameters. The results showed that the greater the strength of adhesive mortar, the smaller the thickness of new and old interface, the smaller the replacement rate of recycled aggregate, and the smaller the particle size of aggregate, the greater the compressive strength of recycled concrete. Jiang Baoku et al. [8] used ANSYS simulation software to simulate the axial tension and axial compression of recycled concrete at the meso level, and studied the influence of brick content on it. The results showed that with the increase of brick content, the initial elastic modulus and peak stress decreased, but the chloride ion concentration in the specimen increased. Lu Bo et al. [9] used ANSYS finite element software, combined with Monte Carlo method and Fuller grading theory to generate numerical simulation specimens, and carried out finite element numerical simulation on cube uniaxial compression test and prism uniaxial compression test of fly ash recycled concrete. The results showed that the micro cracks of fly ash recycled concrete first appeared in the interface transition zone with relatively weak strength. Duan Dongxu et al. [10] used ABAQUS to establish two-dimensional and three-dimensional random aggregate models of recycled concrete, and carried out numerical simulation under uniaxial tension and compression. It was concluded that under uniaxial tension or compression load, the strength of new and old hardened mortar had a greater impact on the mechanical properties of recycled concrete specimens, while the strength of inner and outer interface areas had a smaller impact. Li Long et al. [11] established a finite element model of recycled concrete based on the nine-aggregate model, and studied the influence of replacement rate of recycled coarse aggregate and strength of new and old mortar on the strain rate sensitivity of recycled concrete. The results show that when the replacement rate of recycled coarse aggregate increases or the strength of new and old mortar decreases, the elastic modulus and strain rate sensitivity of recycled concrete increase. Anuruddha et al. [12] also studied the influence of hardness of single material and mortar content on mechanical properties of recycled aggregate concrete by uniaxial compression two-dimensional finite element analysis of recycled aggregate concrete specimens. The results show that the compressive strength of Rac decreases with the increase of aggregate stiffness, old ITZ stiffness and mortar parameters. In addition, Zhou et al. [13] used the periodic boundary condition and the overlap criterion of two polygonal aggregates to generate polygonal aggregates, and combined the iterative method with fast Fourier transform to calculate the elastic modulus of recycled concrete. The research shows that the elastic modulus of recycled concrete increases with the increase of total aggregate content and the elastic modulus of new old interface. Xiao et al. [14] proposed an improved lattice model to simulate the fracture process of recycled concrete under tension and compression loads. The results show that the cracks of recycled concrete always appear around the interface transition zone, and then extend to the old hardened mortar part, and then to the new hardened mortar part.

3. Numerical simulation based on interface transition zone

Compared with ordinary concrete, the new interface transition zone of recycled concrete is relatively loose, and the interface width is larger than that of ordinary concrete [15]. Many studies show that the interfacial transition zone has a great influence on the properties of recycled concrete. Li Bangding et al. [16] preliminarily simulated the uniaxial compression test process of recycled concrete using ANSYS,
and the results showed that the strength of cement mortar had a direct impact on the compressive strength of recycled concrete. The bonding interface between recycled aggregate and cement mortar is the weak link of recycled concrete. Improving the bonding interface strength can effectively improve the compressive strength of recycled concrete. Yue Qiang et al. [17] used nonlinear software to simulate the damage process of recycled concrete under uniaxial tension and compression. The results show that in the process of mechanical failure of recycled concrete, there are tensile stress and shear stress concentration in the interface transition zone, and cracks appear first in the interface transition zone between old mortar and natural aggregate. Based on ABAQUS, Xiao Jianzhuang et al. [18] established the finite element model of recycled concrete with nine aggregate models, and numerically simulated the static and low cycle fatigue loading of recycled concrete under uniaxial compression. The results show that the interfacial transition zone is the decisive factor affecting the mechanical properties of recycled concrete. Chen Siying et al. [19] used ABAQUS software to carry out unidirectional compression numerical simulation on interface transition zone models with different porosity, and studied the quantitative corresponding relationship between porosity and elastic modulus of concrete interface transition zone. The results show that the elastic modulus of concrete interface transition zone is non-uniform distribution. Zhang Yingxue [20] used ABAQUS to simulate the mechanical properties of aggregate and mortar, and studied the mechanical properties of interface transition zone under different aggregate sizes. The results show that the larger the aggregate size is, the smaller the compressive strength of interface transition zone is, but the aggregate size has little effect on the elastic modulus of interface transition zone. In addition, it is found that the concrete strength grade has a great influence on the compressive strength and elastic modulus of the interface transition zone. The higher the concrete strength is, the greater the compressive strength and elastic modulus of the interface transition zone are. Yao Zeliang et al. [21] used ABAQUS software to establish the micro structure calculation model of recycled concrete double interface, and studied the compressive strength and peak strain of recycled concrete under uniaxial compression. The results show that there are concentrated tensile stress and shear stress in the interface transition zone, and the interface transition zone is the first to fail. Wang et al. [22] proposed a recycled concrete model which can mesh directly inside the aggregate, and simulated the two-dimensional element. The research shows that with the increase of the thickness of the interface transition zone, the number of cracks in the old interface is more than that in the new interface, and in the simulation study of recycled concrete, the thickness of the interface should be controlled less than 0.8mm to meet the accuracy requirements. Zhou et al. [23] used the finite element method with damage model to simulate the crack propagation process and mechanical properties of recycled concrete specimens under uniaxial compression. The results show that the interfacial transition zone is the weak link of recycled concrete specimens under stress, and its failure mainly begins to form along the old interfacial transition zone and the new interfacial transition zone. Xiao et al. [24] used two-dimensional numerical method to study the stress distribution characteristics of recycled aggregate concrete under uniaxial compression. The results show that the tensile stress and shear stress concentration appear near the new old interface. When the elastic modulus of natural aggregate increases, the tensile stress concentration increases. It also shows that the influence of the content of the old cement mortar on the stress distribution of the new interface is obviously greater than that of the old interface.

4. Existing problems

Effective use of recycled concrete can not only reduce the waste of resources, but also reduce the pressure of government industrial waste treatment, and play a role in environmental protection. But because the tensile strength, compressive strength and elastic modulus of recycled concrete are slightly worse than ordinary concrete, the application of recycled concrete is not very extensive. At present, the research on recycled concrete is mostly focused on the influence of the proportion and strength of composite materials on the properties of recycled concrete, while the research on its interface transition zone is less. It is expected that scholars can do more research on its meso structural characteristics, so as to better understand the relationship between macro and micro recycled concrete, improve the properties of recycled concrete and make full use of it.
For the research of recycled concrete and interface transition zone, most scholars use experimental methods, and few use simulation methods. Because of its complexity, it is difficult to observe the characteristics of the interface transition zone when measuring and studying its properties. Although the experiment is the most intuitive method, if we can consider the various factors, we can choose the simulation method for research. The experiment cost is high, the numerical simulation cost is low, only need to carry on the simulation and data processing on the computer, and can quickly get the results, reduce the test time, reduce the waste of resources. In the future research, more scholars need to use simulation methods to study the properties of recycled concrete and interfacial transition zone more quickly and accurately, so as to improve the previous research results.

5. Conclusions
This paper analyzes the research status of recycled concrete and interface transition zone, and on this basis, analyzes and expounds the existing problems. Recycled concrete is becoming more and more mature in the theoretical research, but it still needs the efforts of many scholars to be applied in practice. At present, recycled concrete has some problems, such as poor durability, insufficient tensile and compressive strength, which need to be solved. To overcome the above problems and realize the large-scale practical application of recycled concrete is a major development direction in the future. The future development trend can be summarized as follows:

(1) More simulation methods are used to study the effect of interfacial transition zone on the properties of recycled concrete. The interface transition zone is the weak link of recycled concrete. The cracks first appear in the interface transition zone, and then spread outward. Therefore, in addition to studying the influence of concrete strength and water cement ratio on recycled concrete, it is also necessary to study how the interface transition zone affects the properties of recycled concrete from the micro perspective, so as to improve the properties of recycled concrete, improve its utilization rate in practical engineering and reduce the waste of resources.

(2) The properties of interface transition zone are studied by simulation method. At present, nanoindentation technology is mostly used to study the interfacial transition region, and numerical simulation is rarely used. This paper explores the influence of Poisson's ratio, thickness of interface transition zone and other factors on the properties of interface transition zone, so as to provide a theoretical basis for improving the complexity and instability of interface transition zone, and finally achieve the purpose of improving the mechanical properties of recycled concrete.

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