Opinion Article

Microstructural study of recycled aggregatesconcrete based on scanning electron microscope technique

Abstract: In this paper, the micro-structure of Recycled aggregates concrete will be comprehensively analyzed and judged according to the performance characteristics of Recycled aggregates concrete materials and the relevant analysis technology of scanning electron microscopy. Based on the microscopic technology of scanning electron microscopy, the research progress of the micro-structure of Recycled aggregates concrete was carried out, and the morphology and distribution characteristics of recycled aggregate particles, pore structure and porosity, the interface combination between recycled aggregate and cement matrix, and the relationship between micro-structure and Recycled aggregates concrete properties were summarized, which provided theoretical support for the future understanding of the micro-structure of Recycled aggregates concrete, increased the understanding of the micro-structure of Recycled aggregates concrete materials, and more systematically understood the application of microscopic analysis methods in Recycled aggregates concrete.
Keywords: Recycled aggregates concrete; scanning electron microscope

1.Introduction

Recycled aggregates concrete is a sustainable building material made from recycled waste concrete or construction waste as aggregate and remixed with fresh cement and admixtures. With the rise of the concept of sustainable development and the increasing pressure on resources and the environment, recycled aggregatesconcrete is receiving more and more attention from the engineering community. However, due to the use of recycled aggregates, the microstructure of recycled aggregatesconcrete is somewhat different from that of conventional concrete. Factors such as binder attachment, calcareous concrete residue, and agglomeration of cementitious materials may exist in recycled aggregates, which can affect the performance and durability of recycled aggregatesconcrete. So it is important to study the microstructure of recycled aggregatesconcrete. The study of its microstructure is of great significance for the in-depth understanding of its performance characteristics and the development of reasonable design, construction and maintenance methods. By observing and analyzing the microstructure of Recycled aggregates concrete, information on the distribution of recycled aggregates, particle morphology, pore structure, and interaction with the cement matrix can be understood, thus revealing the relationship and influencing mechanism between the properties of Recycled aggregates concrete and its microstructure[1-3].

In recent years, with the development and application of scanning electron microscope (SEM) technology, it has become an important tool for studying the microstructure of recycled aggregatesconcrete.SEM technology can provide high-resolution images to help researchers observe and analyze the details of microstructure in recycled aggregatesconcrete, such as particle morphology, pore structure, and interfacial bonding.In this paper, the microstructure study of Recycled aggregates concrete based on scanning electron microscope technology is reviewed according to the relevant literature to lay the foundation for promoting the wide application of recycled building materials and realizing the sustainable use of resources and the sustainable development of the environment.

2.Properties of recycled aggregatesconcrete

Recycled aggregates concrete usually refers to new concrete that is formulated using recycled aggregates to partially or completely replace natural aggregates. Recycled aggregates generally come from abandoned buildings and are crushed, cleaned and screened by machines, and contain natural aggregates, old mortar and a combination of the two[4]. Recycled aggregates concrete technology can realize the recycling of waste concrete, restore some of its original properties, the formation of new building materials products, thus reducing both the number of landfills and simple piles of waste concrete, but also make the limited resources can be reused, with significant economic, social and environmental benefits.

Recycled aggregates are divided into two main categories, one is Recycled aggregates concrete aggregate and recycled brick aggregate, we only consider the classification and application of Recycled aggregates concrete aggregate here: Recycled aggregates concrete aggregate is classified into 0-5mm, 5-10mm, 10-20mm, 16-31.5mm specification models, in which most of their use scenarios are substituting or partially substituting for natural sand, used for sand and gravel bedding, road laying , brick making, concrete mixing, roadbed filling, etc. It is suitable for industrial and civil construction projects, municipal engineering, landscaping, decoration and ornamentation, road projects, sponge city construction projects and so on[6-9].

2.1mechanical property

Hao[10]etal. prepared test blocks with different mix ratios for testing by experimentally using waste bricks to replace natural gravel and waste concrete to replace natural sand. The test results showed that the compressive strength of Recycled aggregates concrete was related to the water-cement ratio, which had a greater effect on the compressive strength at the age of 3 and 7 days, while the effect on the age of 28 days was not obvious. The compressive strengths of the test blocks with different mix ratios were close to each other, ranging from 21 to 25 MPa.

Xiao[11]et al. from Tongji University analyzed the effects of the substitution rate of recycled coarse aggregate on the shape of the stress-strain full curve of Recycled aggregates concrete and the compressive strength, modulus of elasticity, peak and ultimate strain of Recycled aggregates concrete through the uniaxial compressive stress-strain full curve test of Recycled aggregates concrete with different substitution rates of recycled coarse aggregate. The study shows that the overall shape of the stress-strain full curve of Recycled aggregates concrete is similar to that of ordinary concrete, but the stress and strain values at each characteristic point on the curve are different; the ratio of prismatic compressive strength to cubic compressive strength of Recycled aggregates concrete is higher than that of ordinary mud concrete; the peak strain of Recycled aggregates concrete is greater than that of ordinary concrete; and the modulus of elasticity of Recycled aggregates concrete is obviously lower than that of ordinary concrete.

Xu[12]et al. of Zhejiang University successfully formulated C40-C60 high-performance Recycled aggregates concrete by using high-quality mineral admixture and high-efficiency water reducing agent, and used electro-hydraulic servo pressure testing machine to carry out uniaxial compression test on the high-performance Recycled aggregates concrete, measured the stress-strain curve and carried out theoretical analysis, and summarized the mathematical expression for the uniaxial stress-strain curve of the uniaxial compression of the Recycled aggregates concrete, which matches well with the test results. The mathematical expression of uniaxial stress-strain curve of Recycled aggregates concrete is summarized, which is in good agreement with the test results.

2.2 Durability

Based on the results of existing research on the durability of Recycled aggregates concrete and its influencing mechanism, Zhang et al. explored and analyzed the influencing elements of the durability of Recycled aggregates concrete from the aspects of aggregates, water-cement ratio, admixtures, supplementary cementitious materials (SCM), and microscopic morphology and summarized the development law of the performance of Recycled aggregates concrete, and summarized the influences of the mixing amount of recycled aggregates, water-cement ratio, fly ash, and the effect of the admixtures on the seepage resistance of Recycled aggregates concrete.

Zhu[13]et al. conducted an experimental study on the permeability properties of Recycled aggregates concrete by changing the water-cement ratio (W/C of 0.4, 0.5, 0.6) and recycled aggregate admixture (RA of 0, 30%, 60%, 100%), and concluded that the resistance of Recycled aggregates concrete to chloride ion permeability was better than that of ordinary concrete at low water-cement ratios (W/C of 0.4, 0.5) and lower water-cement ratio could effectively improve the resistance of Recycled aggregates concrete to chloride ion permeability. It is concluded that at low W/C ratios (W/C of 0.4 and 0.5), the chloride ion permeability of Recycled aggregates concrete is better than that of ordinary concrete, and that lowering the water-cement ratio can effectively improve the chloride ion permeability of Recycled aggregates concrete.

Zhang[14]et al. compared the differences in the permeability properties of natural concrete and Recycled aggregates concrete under different strengths (C20, C30), water-cement ratios (W/C of 0.42, 0.45, 0.50, 0.55), and sand ratios by means of a concrete permeability test, so as to analyze the factors affecting the permeability properties of Recycled aggregates concrete and conclude that the permeability of Recycled aggregates concrete increases with the increase in the strength class of concrete and decreases with the increase of water-cement ratio, and the permeability of concrete increases sharply when the water-cement ratio of concrete is greater than 0.55.

3. Introduction to scanning electron microscopy technology

3.1Principles and Applications of Scanning Electron Microscopy (SEM)

SEM utilizes a high-energy electron beam interacting with the sample surface to obtain high-resolution images and characterization information. By accelerating the electron beam and focusing it to a very small diameter, a variety of interactions, such as secondary electron emission, reflected electrons, etc., are generated when the electron beam irradiates the surface of Recycled aggregates concrete. The signals generated by these interactions are received by the detector and converted into images or other forms of data. SEM observation allows detailed characterization and analysis of the microstructure of Recycled aggregates concrete.

3.2 Progress of microstructure research on Recycled aggregates concrete

By observing and analyzing the microstructure of Recycled aggregates concrete, information on the distribution of recycled aggregates, particle morphology, pore structure, and interaction with the cement matrix can be revealed. This helps to deepen the understanding of the performance characteristics of Recycled aggregates concrete.

3.2.1 Study on the morphology and distribution characteristics of recycled aggregate particles

Sun[15]et al. conducted an in-depth study on the micro-morphological characteristics and elemental composition of recycled aggregates by means of scanning electron microscopy (SEM) and energy spectrum analysis (EDX) techniques, and analyzed the influence mechanism of recycled aggregates on the performance of concrete. The results show that the morphology of recycled aggregates is diverse and mostly irregular; the surface of recycled aggregates is poorly bonded to the cement paste, which leads to a decrease in the cracking strength; and the fracture interface of the specimens is mainly composed of calcium carbonate and magnesium carbonate. These studies are of great significance for proposing new concrete formulation and control methods, optimizing application techniques, especially new proportion design methods and techniques, and developing new composition systems for concrete.

Li[16]et al. analyzed the flexural compressive strength and micro-morphology of recycled mortar with different particle sizes of recycled aggregate replacing natural mortar step by step by electron microscope scanning technique, and the results showed that: the flexural compressive strength of recycled mortar with recycled aggregate replacing natural sand step by step was larger than that of ordinary mortar, and it increased with the increase of the replacement rate of recycled aggregate; the strength growth of recycled mortar was greatest when the age was 14 d. The strength of recycled mortar was greater than that of ordinary mortar when the natural sand was replaced with recycled aggregate by step by step. The strength of recycled mortar with an age of 14 d increased the most when 100% recycled aggregate replaced natural sand step by step.

Al-Bayati[17]et al. improved the physical and morphological properties of coarse Recycled aggregates concrete aggregates by combining different types of treatments. Scanning electron microscopy (SEM) and energy spectroscopy (ES) analyses were carried out in order to investigate the surface morphology and chemical composition of treated and untreated Recycled aggregates concrete aggregates. The results showed that the physical properties of Recycled aggregates concrete aggregates could be maximized by heat treatment at 350°C in combination with short-term mechanical treatment.

3.2.2 Study of pore structure and porosity

SEM can provide high-resolution images that can reveal the pore structure and pore size distribution of Recycled aggregates concrete. By observing the type, shape and size of the pore structure, the compactness and pore properties of Recycled aggregates concrete can be evaluated and the mechanical properties and durability of the material can be further improved.

Li[18]chose glass fiber to modify the Recycled aggregates concrete with 25% substitution rate, and took different glass fiber volume rate, special environment type and its action time as variables, and carried out compressive, porosity, impermeability and SEM tests on the Recycled aggregates concrete with glass fiber after the action of the special environment, so as to analyze and investigate its damage attenuation law at the microscopic and macroscopic levels on the damage to the Recycled aggregates concrete with glass fiber by the special environment and its damage mechanism. Analyze the damage and damage mechanism of special environment on glass fiber Recycled aggregates concrete from micro and macro level, and explore its damage attenuation law. The results show that: under the action of special environmental species, the glass fiber volume rate of 1.0% reaches the best, compared with the plain concrete, the compressive strength are improved; porosity is reduced; permeability height is reduced.

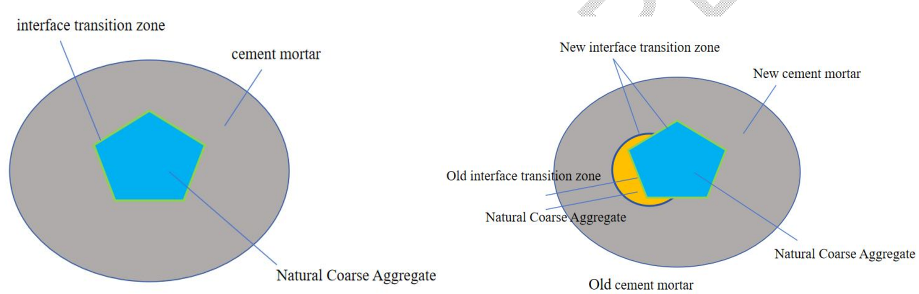
Liu[19]used microscopic tests to study the effect of ceramic sand on the pore structure of cementitious materials, combined with the pore structure parameters measured by microscopic tests, and considered the multi-scale research ideas from microstructure to macroscopic material transport behavior, to study the evolution of the long-term performance of the ceramic powder cementitious materials, and carried out scanning electron microscope tests on the specimens as well as microscopic tests, such as mercury compression. Through the scanning electron microscope test, it was found that the cracks and pores on the surface of the specimen and the transition zone at the cement-mortar interface were gradually filled with hydration products, and the specimen became denser, which led to the improvement of the mechanical and durability properties of the specimen with the increase of the curing time.

Yan[20]based on SEM-EDS analysis of two-dimensional morphology of recycled aggregate and old mortar, recycled aggregate and new mortar and new and old mortar interfaces and corrosion product evolution within the slurry, studied the structural change rule of multiple interfaces of Recycled aggregates concrete under the action of internal corrosion as well as the distribution of corrosion products, and revealed the mechanism of the action of sulfate ion-carrying recycled aggregates on the internal corrosion of concrete. It can be seen from the XRD and SEM-EDS test results that the main corrosion products in the mortar are dominated by calcium alumina, and are mainly concentrated in the vicinity of the interface area between the old and new mortar. With the gradual diffusion of ions, a small amount of gypsum is also contained within the mortar when the sulfate ion content is high.

3.2.3 Study of interfacial bonding between recycled aggregates and cement matrix

SEM By observing the microscopic morphology and characteristics of the interfacial region of Recycled aggregates concrete, the bond between the recycled aggregate and the cement matrix can be assessed. This is important for understanding the interfacial properties of Recycled aggregates concrete, the reinforcement mechanism, and the damage and destruction in the interfacial region.

Compared with ordinary concrete, Recycled aggregates concrete has a more complex microstructural form, which mainly includes: new cement mortar, natural aggregate in recycled aggregate, old cement mortar carried by recycled aggregate, the interface between old cement mortar and new cement mortar, and the interface between natural aggregate within the recycled aggregate and the old cement mortar, as shown in Figure 1.



(a) Natural concrete microstructure(b) Natural concrete microstructure

Fig.1 Schematic diagram of the internal structure of Recycled aggregates concrete[21]

Poon[22]et al. prepared concrete specimens by using recycled normal strength concrete aggregate, recycled high performance concrete aggregate and natural aggregate as controls and investigated their properties. Scanning electron microscope observations showed that the interfacial region between recycled normal strength concrete aggregate and cement consisted mainly of loose and porous hydrates, whereas the interfacial region between recycled high performance concrete aggregate and cement consisted mainly of dense hydrates. The findings can be explained by the differences in porosity and pore structure of the two types of aggregates and the possible interactions between the aggregates and the cement paste.

Sidorova[23]A et al. in the course of their research suggested that the structure of the cement paste matrix is close to the aggregate and different from the rest of the cement paste. Possible interfacial transition zone (ITZ) formation was compared by nanoindentation tests and scanning electron microscopy (SEM), as well as three different properties of aggregate inclusions: limestone (NA), Recycled aggregates concrete aggregate (RCA), and recycled ceramic aggregate (RC). It is shown that the nature of the aggregate and the W/C conditions determine the microstructural properties of the aggregate-cement paste interface and the mechanical properties of the ITZ.

Rao[24]et al. discussed the ITZ properties of RAC in terms of hydration compounds, anhydrous cement, and porosity by SEM. Specific steps for scanning electron microscopy (SEM) specimen preparation were also discussed and the effect of these parameters on concrete strength was further elaborated.

3.2.4 Study on the relationship between microstructure and properties of Recycled aggregates concrete

Wang[25]et al. modified recycled aggregate concrete by the dual modification method of “pre-impregnation mixing and blending”, and tested and analyzed the physical properties of recycled aggregate pre-impregnated with nano-silica sol and the mechanical properties of recycled aggregate concrete after the dual modification, and microscopically characterized the modified recycled aggregate concrete by using SEM, EDS, EM and EDS. SEM and EDS were used to characterize the modified recycled aggregate concrete.The EM and EDS characterization showed that the incorporation of nanosilica sol could accelerate the hydration reaction, reduce the Ca/Si, and generate a large number of C-S-H(I)-type gels, so that the new and old cement pastes, as well as the pastes and aggregates are closely linked, and the strength of the recycled aggregate concrete has been significantly improved.

Yue[26]et al. prepared and tested concrete specimens after immersion in seawater for 0, 30, 60 and 4 months at different replacement rates of 8%, 12% and 16%, respectively. The aim was to investigate the microstructure and basic properties of recycled aggregate concrete under seawater corrosion and the basic properties of recycled aggregate concrete (RAC) such as compressive strength, modulus of elasticity and chloride penetration depth. Scanning electron microscopy (SEM) was utilized to reveal the microstructure of Recycled aggregates concrete aggregate (RCA) for seawater corrosion. The results show that higher RCA content implies higher porosity, lower strength, lower compressive strength, and lower compressive strength and chloride penetration resistance.

Liu[27]et al. investigated the effects of SSP and metakaolin (MK) compounding on the mechanical properties and microstructure of RAC. SEM microtests showed that SSP and MK blending reduced the peak strength of Ca(OH)2 and generated more additional C-S-H gels as well as increased the percentage of high-density C-S-H in C-S-H, resulting in a significant improvement of the microstructure and interfacial transition zone in the later stages of the RAC, which was attributed to the fact that SSP and MK blending showed better volcanic ash activity and microaggregate filling effect.

4. Conclusion

4.1 Problems and challenges

Some progress has been made in the application of scanning electron microscopy (SEM) in the microstructure of Recycled aggregates concrete, but there are still some problems and challenges in the following areas:

Image interpretation: the interpretation of SEM images requires some expertise and experience in the micro-characterization of Recycled aggregates concrete. Accurate interpretation and quantitative analysis of complex concrete microstructures, such as cemented regions and phase interfaces, are still challenging.

Resolution and Observation Depth: SEM can provide high-resolution surface images, but its observation depth is limited. Detailed information can be obtained when observing the sample surface, but for understanding the internal structure and pore characteristics, additional processing such as sample sectioning is required.

Resolution and Depth of Observation: SEM provides high-resolution images of surfaces, but its depth of observation is limited. Detailed information can be obtained when observing the surface of the sample, but for understanding the internal structure and pore characteristics, additional processing such as sample sectioning is required.

4.2 Future directions and research priorities.

Development of quantitative analysis methods: Future research could focus on the development of more accurate and reproducible quantitative analysis methods to utilize the information in SEM images to assess the performance metrics of the microstructure of Recycled aggregates concrete, such as porosity, pore size distribution, and cementitious strength.

Application of three-dimensional microscopy: Traditional SEM techniques are mainly based on two-dimensional surface images, and in order to better understand the microstructure of Recycled aggregates concrete, the application of three-dimensional microscopy techniques such as focused ion beam (FIB) cutting and computed tomography (CT) can be explored.

Integration of multimodal microscopy: Combining SEM with other microscopy techniques, such as transmission electron microscopy (TEM), atomic force microscopy (AFM), etc., can provide more comprehensive information on the microstructure of Recycled aggregates concrete.

In-depth study of recycled aggregate properties: SEM can be used to observe and analyze the characteristics of recycled aggregates, such as particle morphology, surface condition, etc.. Studying the properties of recycled aggregates can help optimize the proportioning design of Recycled aggregates concrete and improve the production process.

Overall, future research can be devoted to solving the problems of sample preparation, image interpretation and resolution, developing more advanced quantitative analysis methods, and integrating multimodal microscopy techniques to gain insights into the microstructure and material properties of Recycled aggregates concrete.

References

[1] Li Y, Huang M, Jiang T. Research on mechanical properties of recycled concrete based on fine microstructure[J]. Concrete,2022(08):67-70.

[2] Chen Y, Sun Z, Xiao J. Characteristics of interface structure of recycled concrete and its improvement measures[J]. Concrete,2004(02):10-13.

[3] Du J. A review of microstructure of recycled concrete[J]. Guangdong Building Materials,2010,26(04):55-58.

[4] Xiao J, Liu Q, Li W et al. Research on fine microstructure and damage mechanism of recycled concrete[J]. Journal of Qingdao University of Technology, 2009, 30(4).

[5] Geng O, Chen Z, Gu RJ. Development law of interface microstructure of recycled coarse aggregate concrete[J]. Journal of Building Materials, 2012, 15(3):340-344.

[6] Yu Y, Hu H, Pei Q et al. Research on mechanical properties and microstructure of recycled micro-powder-recycled aggregate concrete[J]. Functional Materials,2022,53(08):8147-8152+8175.

[7] Tong X, Wang S. Mechanical properties and microstructure analysis of concrete with recycled aggregate from iron tailing sand[J]. Concrete,2021,No.375(01):91-93+97.

[8] Classification and application of recycled aggregates[J]. Jiangxi Building Materials,2020,No.260(09):192.

[9] WangX,LI L,Wang W. Performance characteristics and application prospect of recycled concrete[J]. Journal of Henan University of Technology(Natural Science Edition),2012,31(01):95-99+108.DOI:10.16186/j.cnki.1673-9787.2012.01.010.

[10] Hao T, Shi L, Chen J. Experimental study on physical and mechanical properties of recycled concrete[J]. Building Structure,2013,43(01):73-75.

[11] Xiao J. Experimental study on uniaxial compression stress-strain of recycled concrete[J]. Journal of Tongji University (Natural Science Edition),2007(11):1445-1449.

[12] Xu Y, Shen J. Experimental study on high performance of recycled concrete[J]. Concrete,2007,No.215(09):37-38+41.

[13] Zhu Y, Chen J, CHEN Jianfeng, WANG Peng. Research on the effect of water-cement ratio and recycled aggregate admixture on the permeability performance of recycled concrete[J]. Journal of Nantong Vocational University,2016,30(04):101-104.

[14] Zhang L, Liu B. Experimental study on permeability of recycled concrete[J]. Journal of Hefei University of Technology (Natural Science Edition),2009,32(04):508-510+527.

[15] Sun L, Ren F, Ge D et al. Micromorphological characteristics and energy spectrum of recycled aggregate concrete[J]. Journal of Beijing Jiaotong University,2014,38(01):24-28.

[16] Li D, Zhang Y, Deng Y et al. Effect of step-by-step substitution of recycled fine aggregate on strength and microform of recycled mortar[J]. Silicate Bulletin,2016,35(11):3876-3880.DOI:10.16552/j.cnki.issn1001-1625.2016.11.066.

[17] Al-Bayati H K A, Das P K, Tighe S L, et al. Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate[J]. Construction and Building Materials, 2016, 112: 284-298.

[18] Li, H. Research on compressive and impermeable properties of glass fiber recycled concrete under special environmental effects [D]. Donghua University of Science and Technology,2022.DOI:10.27145/d.cnki.ghddc.2022.000521.

[19] Liu Z. Experimental study on the effect of ceramic recycled sand on the pore structure and long-term performance of cementitious materials [D]. East China Jiaotong University,2022.

[20] Yan X. Research on the internal corrosion behavior of recycled aggregate carrying sulfate ions on concrete [D]. Chang'anUniversity,2022.DOI:10.26976/d.cnki.gchau.2022.000015.

[21] Wen B. Research on the influence of recycled coarse aggregate properties on the crack resistance of new interface of recycled concrete[D]. Nanchang University,2024.DOI:10.27232/d.cnki.gnchu.2024.002477.

[22] Poon C S, Shui Z H, Lam L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates[J]. Construction and building materials, 2004, 18(6): 461-468.

[23] Sidorova A, Vazquez-Ramonich E, Barra-Bizinotto M, et al. Study of the recycled aggregates nature's influence on the aggregate–cement paste interface and ITZ[J]. Construction and Building Materials, 2014, 68: 677-684.

[24] Rao M C, Bhattacharyya S K, Barai S V, et al. Microstructure of recycled aggregate concrete[J]. Systematic Approach of Characterisation and Behaviour of Recycled Aggregate Concrete, 2019: 209-247.

[25] Wang W, Shao P, Hu Y et al. Study on the effect of nanosilica sol on the mechanical properties of recycled aggregate concrete and micro-mechanism[J]. Journal of Qiqihar University (Natural Science Edition),2023,39(03):68-73.

[26] Yue P,Tan Z,Guo Z. Microstructure and Mechanical Properties of Recycled Aggregate Concrete in Seawater Environment[J]. The Scientific World Journal,2013,2013.

[27] Liu Y, Zhou C. Research on mechanical properties and microstructure of steel slag powder-metakaolin recycled concrete[J]. Industrial Building,2022,52(02):133-138+157.