Experimental analysis of damage mechanism and shrinkage performance of recycled concrete

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Abstract. This article analyzes the interface structural features and damage mechanism of recycled aggregate concrete. Recycled aggregates are divided into three types by particle shaping. Through the experiments, the shrinkage performance of recycled concrete is analyzed under the conditions of different cement content and the replacement rate of recycled coarse aggregate. The experimental results show that A is the worst, inferior to NA ordinary concrete; C is the best, superior to NA ordinary concrete.

1. Introduction
On a conservative estimate, the annual production of waste concrete in China is about 100 million tons. Only a tiny amount of low-level waste concrete is recycled in the non-bearing structures, such as base courses of roadbeds, and most of it is landfilled or piled up, which pollutes the environment and wastes resources. Meanwhile, the annual concrete production in China is up to 1.5 to 2 billion cubes, and the sand-gravel aggregates required exceeds 10 billion tons. Over-exploitation of sand and gravel has caused landslides and riverbed realignments, destroying the sustainable development of the ecological environment of aggregates’ native place. In some areas of China, the high-quality natural aggregates (river sand, pebbles) have been exhausted. Hunting for alternative aggregate sources, treatment and disposal of waste concretes, and the concern for the sustainable development of the environment have set off a recycling research upsurge of waste concrete[1].

With the rapid development of the society and the reconstruction of the infrastructure, the demand for concrete is increasing, and the treatment of a large number of demolished building wastes will bring some harm to the environment. Therefore, this paper put forward the basic idea of recycled aggregate concrete, and hopes to replace partially ordinary concrete with recycled aggregate concrete. It can not only meet the social needs, but also reduce the harm to the environment and realize the recycling of resources, and recycled aggregate concrete research also become the focus of social research nowadays. However, due to the large amount of old adhered mortar in recycled aggregate, it has certain defects in mechanical properties compared with ordinary concrete. At present, the processing mechanism of recycled aggregate concrete technology is not perfect, and there are many bottlenecks that need to be broken in order to improve various mechanical performance indexes. All of these limit the development of recycled aggregate concrete to a large extent. So far, recycled aggregate concrete has been mostly used in some non-load-bearing components or road surfaces. The study on the damage mechanism and modification method of recycled aggregate concrete are of great significance for improving the destructive of recycled aggregate concrete and strengthen its application in engineering[2, 3].
According to the related research, it is found that either the tensile failure or the compression failure of the recycled aggregate concrete is manifested by the fracture of the old adhered mortar and the interface transition zone. The initial micro cracks in the process are usually first appeared in the interface transition zone, and then extend to the mortar area. Therefore, the interface transition zone is the weakest link of recycled aggregate concrete, and the main factor causing this phenomenon is the existence of old mortar. To a large extent, the old mortar influences the difference in quantity, distribution and performance of interface transition zone. In recent years, many scholars have done research on recycled aggregate concrete, and have made a series of research achievements in improving the performance of recycled aggregate and the strength of recycled aggregate concrete. This paper will sort out and summarize these achievements. Through the experiments, the shrinkage performance of recycled concrete is analyzed under the conditions of different cement content and the replacement rate of recycled coarse aggregate[4].

2. Interface characteristics and damage mechanism of recycled concrete

The interface in concrete is a loose porous structure, where the concentration and orientation of much Ca(OH)$_2$ exist, which is the weakest link in concrete, affecting significantly the mechanical property and durability of concrete. Recycled aggregate is made of processed waste concrete, often some hardened set cement or mortar appear on the surface of the aggregate. Thus, the recycled aggregate itself is a composite, and there are more interfaces in the concrete prepared by the recycled aggregate than ordinary concrete: Aggregate/old mortar interface, aggregate/new mortar interface, old mortar/new mortar interface, and interface intersection. The existence of multiple interface structures causes recycled concrete to use a large amount of water, with a low strength after hardening and low elasticity modulus. At the same time, the anti-permeability, freezing resistance, carbonization resistance, shrinkage, creeping, and chloride ion penetration resistance and other endurance qualities of the recycled concrete are also lower than those of ordinary concrete. The concrete itself is made of cement mortar, interfacial transition zone and aggregate. The strengthening phase is aggregate, and the matrix phase is cement concretion -cement mortar. Therefore, with respect to recycled concrete, its strengthening phase is the recycled aggregate and its matrix phase is the cement mortar. In accordance with the structural characteristics of recycled concrete, it is possible to enhance the combination of various interfaces, the combination of interface intersections, and the cohesion of recycled aggregates in two strengthening ways, that is, improving the properties of recycled aggregate and the performance of cement mortar, to increase the performance of recycled concrete.

The application of recycled concrete can meet the strength requirements, as well as the durability requirements. Only in this way, can the structural safety of recycled concrete be guaranteed. The performance deterioration degree of recycled concrete is related to the quality and replacement rate of the used recycled aggregate. The performance of Type I recycled aggregate concrete is superior to that of Type II recycled aggregate concrete, and better than that of Type III recycled aggregate concrete: the higher the replacement rate of recycled aggregate, the greater the performance deterioration degree of recycled concrete. Generally speaking, provided that the content of cementing material is determined, the lower the strength of recycled concrete, the worse the durability will be. In real life, it often happens that mixture of recycled concrete made from recycled aggregates has a large water consumption, a low strength and low elastic modulus, and its anti-permeability, freezing resistance, carbonization resistance, shrinkage, creeping, and chloride ion penetration resistance and other endurance qualities are also lower than those of ordinary concrete. The main reasons why the performance of recycled concrete is low is that there are structures with multiple weak interfaces in recycled concrete[5]. See Figure 1 for typical photos of natural aggregate and recycled concrete aggregate.
Recycled aggregate is made of processed waste concrete (also known as the original concrete), often some hardened set cement or mortar exists on the surface of the aggregate. Thus, the recycled aggregate itself is a composite, and inside there are some interfaces which can be called old interface. The hardened cement paste or mortar in the concrete (hereinafter collectively known as slurry) is continuous, while the coarse aggregate is discontinuous. However, the natural coarse aggregate in the recycled aggregate is generally continuous, while the slurry is discontinuous, the old interface only exists locally. Previous researches generally thought of it as a closed interface along the coarse aggregate surface, so many scholars think that the interface in recycled concrete includes the old interface and the old slurry-new slurry interface. In fact, the aggregate is made of a local material, and the aggregate in an area changes little. When the natural aggregate is replaced by some recycled aggregate, the new surface (excluding the slurry) in the recycled aggregate is similar to the surface of the natural aggregate. At this time, there are three interface structures in the recycled concrete: the old interface, the old slurry-new slurry interface, and the natural aggregate-new slurry interface. Secondly, recycled concrete is mostly concrete where natural aggregate is replaced by recycled aggregate partially. When many researchers carry out research on the interface structure of recycled concrete, they normally select the weakest interface randomly between aggregate and slurry from recycled concrete. They think that this is the old interface in the recycled aggregate; to some extent, this research method is uncertain and blind. Because even ordinary concrete, due to the internal stratification, the structure of the coarse aggregate differs from those of the upper and lower interfaces perpendicular to the pouring direction. Generally, the upper interface is dense, while the lower interface structure is relatively loose. The interface selected subjectively and randomly is not necessarily an old interface, so a more scientific interface research method needs establishing[6].

3. Experimental analysis of shrinkage properties of recycled coarse aggregate concrete

3.1. Principle and process of tests
This contact shrinkage test is adopted in the test to measure the shrinkage ratio of unconstrained concrete under the conditions of specified temperature and humidity. Experimental process:
(1) Test-piece specification: 100mmx100mmx515mm, with an embedded probe, cured to the valid period of standard.

Figure 1. Natural aggregate (a) and recycled concrete aggregate (b) (c) (d).
(2) Placed in a shrinkage lab with a room temperature of 20±2°C and the relative humidity of 60±5%.
(3) The zero point of the expansion and shrinkage gauge is corrected by a standard bar and readings are taken 3 times at every turn.

3.2. Classification of recycled aggregate
The waste concrete is simply crushed into Type II recycled coarse aggregate by a jaw crusher; Type II recycled coarse aggregate is subjected to the primary shaping and secondary shaping through a particle shaper to obtain the standard Type I recycled coarse aggregate and Type I recycled coarse aggregate. In this article, Type II recycled coarse aggregate is represented by A; standard Type I recycled coarse aggregate is represented by B; Type I recycled coarse aggregate is represented by C.

3.3. Test results
According to Standard for Test Methods of Long-term Performance and Durability of Ordinary Concrete, the shrinkage ratio and test results of test piece are shown in Figures 2 and 3. Among them, the cement contents are taken to be 350kg/m³ and 500kg/m³ respectively.

![Test data map of shrinkage rate of recycled concrete with a cement content of 350kg/m³.](image)

**Figure 2.** Test data map of shrinkage rate of recycled concrete with a cement content of 350kg/m³.

3.4. Analysis of test results
The test conclusions gained through the analysis of effects of particle shaping and recycled coarse aggregate’s replacement ratio on the shrinkage properties of recycled concrete are as follows.

(1) The shrinkage performance of A recycled concrete is the worst, inferior to that of NA ordinary concrete; the shrinkage performance of B recycled concrete is close to that of NA ordinary concrete; C recycled concrete has the best shrinkage performance, superior to that of NA ordinary concrete. Compared with A recycled concrete, the 60d shrinkage ratio of B and C recycled concrete is reduced by 15% -40% and 20% -40%.[7]

(2) The shrinkage ratio of A recycled concrete is increased as the replacement rate increases; the shrinkage rate of B recycled concrete changes little as the replacement rate increases; the shrinkage rate of C recycled concrete is decreased as the replacement rate increases.
4. Conclusions

(1) There are more interfaces inside the recycled concrete: aggregate/old mortar interface, aggregate/new mortar interface, old mortar/new mortar interfaces, and interface intersections. The residual adhered mortar on the surface of recycled coarse aggregate will affect the mechanical properties and durability of recycled concrete. Recycled concrete is a multi-phase composite, and the random distribution of multiple interfaces inside makes the research of the interface structure more difficult, thus preventing the study of the property damage mechanism of recycled concrete.

(2) Particle shaping can significantly improve the quality of recycled coarse aggregate and increase the shrinkage performance of recycled concrete. Shrinkage performance of recycled coarse aggregate concrete: A is the worst, inferior to NA ordinary concrete; C is the best, superior to NA ordinary concrete.

References

[1] ZHANG Xue-bing, DEG Shou-chang, DENG Xu-hua, et al. 2005 Experimental Research on a Few Main Factors Influencing Strength of the Recycled Concrete[J] Natural Science Journal of Xiangtan University 27(1) 129-133

[2] Li Qiuyi, Li Yunxia, Zhu Chongji 2005 The Influence of a Particle Shape Correcting Technique in Properties of Recycled Coarse Aggregate [J] Materials Science and Technology 13(6) 579-281,585

[3] ZHU Chong-ji, LI Qiu-yi, LI Yun-xia 2007 The Affection by Aggregate-shaping on Durability of the Recycled Aggregate Concrete[J] China Building Materials Science & Technology 16(3) 6-10

[4] CHEN Jian-liang, NI Zhu-ping 2011 Strengthening Treatment to Improve the Performance of Recycled Aggregate Concrete[J] Low Temperature Architecture Technology 33(2) 14-16

[5] DU Ting, Li Hui-qiang WU Xian-guo 2002 Experimental Study on Strengthening Concrete Recycled Aggregate[J] New Building Materials 29(3) 6-8

[6] WANG Zi-ming, PEI Xue-dong, WANG Zhi-yuan 1999 Improving the Strength of Mornar with Polymer Emulsion for the Waste Concrete Aggregate[J] Concrete 2 44-47

[7] ZHAO Wu, FENG Zhou-xu 2006 Research on the Strengthening Mechanism of Vibration Mixing of Recycled Concrete[J] Concrete 8 17-20

Figure 3. Test data map of shrinkage rate of recycled concrete with a cement content of 500kg/m³.