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Experimental study on mechanical behaviors of concrete with large-size recycled coarse aggregate

Tan Li [a,b], Jianzhuang Xiao [a,*], Cimian Zhu [a], Zheng Zhong [b]

[a] Department of Structural Engineering, Tongji University, Shanghai 200092, PR China
[b] School of Aerospace Engineering and Applied Mechanics, Tongji University, Shanghai 200092, PR China

HIGHLIGHTS

- RAC with large-size recycled coarse aggregates was designed, mixed and tested.
- Different strength indexes and failure pattern of this type RAC were investigated.
- The relationship of LRCA incorporation rate and cube compressive strength was established.

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ABSTRACT

In this paper, a new type of recycled aggregate concrete (RAC) with waste concrete as large-size recycled coarse aggregates (LRCA) was designed and prepared. Due to the maximum size of LRCA being 80 mm, the waste concrete crushing process is simplified and therefore has the advantage of high production efficiency. In this paper, strength indexes and failure pattern of this type RAC were experimentally studied. Research parameters included the incorporation rate of LRCA, the maximum size of LRCA, the original strength of waste concrete and the strength of corresponding natural aggregate concrete (NAC). Cube compressive test shows that the difference between cube compressive strength of concrete with LRCA and that of corresponding NAC is small. When the maximum size of LRCA is 80 mm, and the incorporation rate of LRCA reaches 40%, the cube compressive strength is only decreased by 14%. When the incorporation rate of LRCA is lower than 30%, no significant reduction appears in cube compressive strength. The ratio of axial compressive strength to cube compressive strength of RAC with 80 mm maximum size of LRCA is 12% lower than that of corresponding NAC. The difference of splitting tensile strength between this type of RAC and corresponding NAC is lower than 10%. It is also observed that the cracking surface of crushed specimens often passed through the LRCA.

1. Introduction

In recent years, environmental protection and waste recycling have become hot issues of common concern in the international community. The generated construction waste due to the global building (structure) removal and demolition, war, earthquakes etc. is becoming huge. Among them, the most is waste concrete. In the mainland of China, about 500 million tons of waste concrete annually in the past 3 years. In the United States, approximately 136 million tons of waste were generated by construction and demolition activities, of which only about 28% were recycled [1]. In Britain, each year building demolition will produce about 110 million tons of construction waste, which accounts for more than 60% of the UK's total waste [2]. Thus, how to recycle waste concrete becomes an issue which having social, economic and environmental significance. And it becomes one of the forefront issues in the area of civil engineering.

Concrete with ordinary size of recycled coarse aggregate (RCA) has been well investigated and compared with concrete with natural coarse aggregates (NCA) [3–5]. Generally, the maximum size of RCA obtained by crushing and other processing is less than 31.5 mm. At present in civil engineering, recycled aggregate concrete (RAC) has not been widely applied. Euchar [6] pointed out that in order to obtain RCA with better quality requires a high cost. This may prevent the RAC widely being applied to engineering structures. Zhu and Li [7] proposed the program of recycled concrete with broken waste concrete block. Wu et al. [8] divided waste concrete to 500 mm or longer segments, the cross-sectional dimension of which were ranged $50 \sim 300$ mm, then used them

* Corresponding author.
E-mail address: jzx@tongji.edu.cn (J. Xiao).

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to replace part of concrete in steel stub columns to cast thin-walled steel stub columns filled with demolished concrete segment/lump. It has been observed that compared with steel tubular columns filled with natural aggregate concrete (NAC), the compressive bearing capacity of this component did not significantly reduce, which is an alternative attempt of using demolished concrete segments/lumps in concrete construction.

Concrete with LRCA, initiated and studied in this paper, is proposed using RCA which obtained through preliminary crushing. The maximum size of RCA can be 80 mm or larger. According to Chinese specification, the biggest size of aggregates used in hydraulic engineering is 150 mm. The maximum size of RCA studied in this paper was 80 mm. Generally, current RCA production includes pretreatment (hammering, cutting and sorting), first-stage crushing and screening, second-stage crushing and screening or even third-stage crushing and screening. In the production of LRCA, compared to normal size RCA, second-stage crushing and screening or third-stage crushing and screening are generally not needed. This lead to saving time and energy. Larger aggregate size and fewer number of crushing time also reduce the formation of fine particles. Therefore, concrete with LRCA can greatly improve the utilization of waste concrete, and can significantly reduce the production cost. For these reasons, the superiority in environmental protection and resource utilization is self-evident. Due to the large size of RCA, this kind RAC has great practical value in massive concrete structure and some reinforced concrete structure with a lower reinforcement ratio. For example, this type RAC can be applied in pile foundation platform, massive reinforced concrete members and foundation pit support structure.

Due to the advantages of LRCA in environmental protection and economic aspect, it is necessary to study the mechanical properties of this kind concrete with LRCA. This paper, by comparing some strength indicators between normal concrete and concrete with LRCA, tries to demonstrate the feasibility that this kind concrete can be used in practical engineering, and looks for a suitable design method for this new kind concrete.

2. Materials properties

The cement used in the experiment was Grade 42.5 ordinary Portland cement. Natural coarse aggregate (NCA) was basalt gravel. Fine aggregate was river sand with a fineness modulus of 2.7, ranked in zone II of medium sand. The clay content was 0.9%. The clay lump content was 0.2%. Water was tap water. In order to increase the workability of concrete, SBTJM-10 (retarding, pumping) superplasticizer was added. The water reducing rate was 18.4%.

LRCA were prepared by crushing waste concrete components with an age of 51 days. The jaw crusher was used to crush waste concrete to produce LRCA. The maximum size of LRCA used in the experiment was 80 mm, which was determined by comprehensive consideration with the advantage of large size and the difficulty for future application. The cube compressive strength of waste concrete is shown in Table 1. Some physical properties of LRCA were measured before the experiments. The physical properties of LRCA are summarized in Table 2. When the maximum size is 50 mm, the saturated water absorption of LRAC is between 3.73% and 4.18%. When the maximum size is 80 mm, the saturated water absorption of LRAC is between 3.35% and 4.18%.

When the maximum size was 80 mm, the LRCA was graded into two parts, i.e., 25 ~ 40 mm and 40 ~ 80 mm. According to Ping-Funk equation [9–13], calculated mass ratio of two parts is 50:50. In order to observe the fracture of LRCA in cracked specimens, some LRCA were soaked in red ink, and each experiment included a specimen containing red-colored LRCA, the incorporation rate of which was 30%.

Table 1
Cube compressive strength of waste concrete.

Strength grade	C30*	C30	C40
Tested strength/MPa	30	34	43

* Only be used in the production of LRCA with the maximum size of 50 mm.

Table 2
Physical properties of LRCA.

Apparent density/kg·m^{-3}	Crushing index/%	Moisture content/%
2520	19.89	1.1 ~ 1.2

3. Production process

LRCA is much larger than natural aggregate. This makes it like a piece of concrete block rather than an aggregate, so that it cannot be considered to replace the natural coarse aggregates (NCA) only. Previous tests [7] showed that if only replaced NCA, due to the obvious reduction in the content of NCA, leads to serious degradation of the mechanical properties of recycled aggregate concrete (RAC). Thus, in the study, the mass of LRCA mixed with NAC was described and measured by an incorporation rate, instead of a replacement percentage. Comparison between the two substitution patterns is illustrated in Fig. 1.

The incorporation rate of LRCA is controlled by mass, which is determined by the following equation.

$$r_{LRCA} = \frac{m_{LRCA}}{m_{NAC}} \times 100 \tag{1}$$

In which,

r_{LRCA}—the incorporation rate of LRCA (%);
m_{LRCA}—the mass of incorporated LRCA (kg);
m_{NAC}—the mass of corresponding NAC (kg).

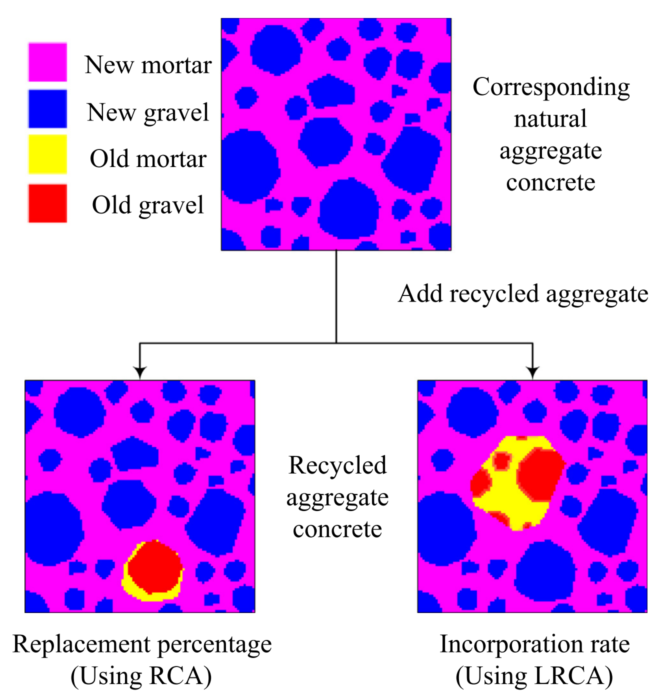

Fig. 1. Comparison of the two substitution patterns.