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Building application of recycled aggregate concrete for upper-ground structural elements

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HIGHLIGHTS

- Recycled fine aggregate concrete was first applied to the upper structure of a real building.
- Effective technology of producing energy-saving mid-quality recycled aggregate was developed.
- New technology of producing high-quality recycled fine aggregate was developed.
- Combination of the above two recycled aggregates enables a recycled aggregate concrete applicable to building structures.

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ABSTRACT

Application of the recycled aggregate is a promising technology for resource saving and low environmental impacts, which is more effectively performed when recycled fine aggregate is used in addition to recycled coarse aggregate. Use of the recycled fine aggregate for the upper structures, however, shows minor progress because of the trade-off in aggregate quality and emission of fine particles. Two effective technologies, production of energy saving mid-quality recycled aggregate and high-quality recycled fine aggregate, presented in this paper enabled the application of the mid-quality recycled aggregate to the upper structure for the first time in Japan.

1. Introduction

Recycled aggregate concrete is a major technology of reducing environmental burdens enabling resource saving by recycling the concrete debris as an aggregate. Particularly in Japan, several production technologies capable of manufacturing high-quality recycled course aggregate have been developed and the recycled course aggregate concretes were applied to the upper structure of buildings on a trial basis [1,2]. Recycled fine aggregate, however, requires more production energy than that of the recycled coarse aggregate to ensure the required quality level when applied to upper structure of buildings as a part of the recycled aggregate concrete. Hence it has been mainly used for piles and underground structures and cases applied to the upper structure of buildings are few. However, it is still important for the materials flow ensuring higher recycling rate to establish the application technology of the recycled fine aggregate for a wider dissemination.

In this context, two technologies including one enabling the use of mid-quality recycled fine aggregate in the upper structure of buildings and the other capable of manufacturing high-quality recycled fine aggregate applicable to nuclear power plant constructions have been developed. The mid-quality recycled fine aggregate, while having a quality inferior to that of the normal fine aggregate, was used as a recycled aggregate concrete and applied to the upper structure of a building on a trial basis. This paper briefly shows the manufacturing technology and the results of the one-year durability follow-up check of the recycled aggregate concrete applied to real structure.

2. Technical requirements and solutions

Related Japanese standards for recycled aggregate and recycled aggregate concrete are shown in Table 1. As a view of the material flows, it is more efficient to reuse not only recycled coarse aggregate but also recycled fine aggregate. Hence a new technology capable of using recycled fine aggregate has been developed. Two major characteristics of the recycled aggregate technology are as follows.

First, crack control of concrete can be made with the mid-quality recycled aggregate. The mid-quality recycled aggregate exhibits advantages including lower manufacturing energy than that of high-quality recycled aggregate and reduced production of

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Table 1
Japanese standards for recycled aggregate and recycled aggregate concrete.

Japanese standard	Aggregate				Applicable elements
	Water absorption of aggregate (%)		Quality	Consumption energy	
	Coarse	Fine			
JASS 5N[a]	≦2.0	≦3.0	Highest	Largest	All elements[c]
JIS A 5021[b]	≦3.0	≦3.5	High	Large	All elements
JIS A 5022[b]	≦5.0	≦7.0	Middle	Middle	Only mat, pile, etc.
JIS A 5023[b]	≦7.0	≦13.0	Low	Lower	Temporary use only

[a] Japanese Architectural Standard Specification Reinforced Concrete Work at Nuclear Power Plants.
[b] Recycled aggregate standard by quality class.
[c] Including those of nuclear power plants.

by-product powder. However, the major drawback of large drying shrinkage has limited the application fields to underground construction such as piles. Crack resistance equivalent to that of normal concrete was attempted using an expansive agent (JIS A 6202 Expansive additive for concrete). Major components of this admixture comprises calcium-sulphoaluminate-type and lime-type posing expansive effects due to formation of ettringite and calcium hydroxide during hydration reactions.

Second, the obtained high-quality recycled aggregate met the requirements specified in JASS 5N (Japanese Architectural Standard Specification JASS 5N Reinforced Concrete Work at Nuclear Power Plants) quality standard. Many aged nuclear power plants are at the stage of demolition and the reduction and reuse of the demolished concrete are the urgent task [3]. When rebuild the nuclear power plants, requirements for the aggregate are very likely to be in accordance to the JASS 5N quality standard. The use of the equipment with a rotary drum mill enabled the recycled fine and coarse aggregate satisfying the JASS 5N quality including absolute dry density, water absorption and grain-size distribution [4].

3. Experiments on the recycled aggregate and the recycled aggregate concrete

3.1. From experiments to the on-site trial

Procedure from concrete demolition to the on-site application is shown in Fig. 1. The resource of the recycled aggregate was concrete debris produced when a 31-year old, 4-storied RC research institute building with a basement built in the same site was demolished. Properties of the original concrete and its constituent materials are shown in Table 2. The concrete debris was crushed into particles with a diameter less than 40 mm at an intermediate processing plant and then separated into high-quality coarse aggregate (hereafter denoted as recycled coarse aggregate H) and mid-quality fine aggregate (hereafter denoted as recycled fine aggregate M) with a wet triturator. Further the recycled fine aggregate M was subjected to a rotary drum milling to obtain high-quality recycled fine aggregate (hereafter denoted as recycled fine aggregate H). These recycled aggregates were used for the recycled aggregate concrete.

The recycled aggregates and the recycled aggregate concrete were subjected to material properties test and mock-up experiment to confirm those performance. Crack resistance was evaluated in terms of penetrating cracks that can be observed with both embedded strain gauges and visual observation.

3.2. Materials used

Physical properties of aggregate and those of other than aggregate are shown in Table 3 respectively. Relationship between absolute dry density and water absorption of typical samples are shown in Fig. 2 and the variation in water absorption by test is shown in Fig. 3.The recycled coarse and fine aggregates H met the quality requirements specified in JIS A 5021 and JASS 5N (absolute dry density more than 2.5 g/cm^3, water absorption less than 3.0%) respectively. The recycled fine aggregate M also met that specified in JIS A 5022 Supplement A (absolute dry density more than 2.2 g/cm^3, water absorption less than 7.0%). The other materials used are shown in Table 4.

3.3. Properties of the recycled aggregate concrete

Fresh properties, strength and length change behavior of the recycled aggregate concrete were studied. The mix proportions of the concrete are shown in Table 5. The targeted fresh properties were slump of 20 cm and air content of 5.0% taking into account the possible loss during transportation.

Test results for the fresh properties are shown in Table 6. All mixes met the targeted values of slump (20.0 ± 2.5 cm) and air content (5.0 ± 1.5%) and the workability of the concrete was satisfactory. Compressive strength of recycled aggregate concrete specimens subjected to the standard curing is shown in Fig. 4. When the water–binder ratio was equal, compressive strength of the specimen was equivalent regardless of the type of aggregate. The length changes until the age of 189 days, according to the restraint method B specified in JIS A 6202 supplement 2 "Testing method of restrained expansion and shrinkage of concrete with expansive additive", are shown in Fig. 5. The length changes showed no differences by the type of fine aggregate and were able to be reduced approx. 200 μm when an expansive agent was applied. Effect of the type of fine aggregate on the drying shrinkage was found to be small compared to that of coarse aggregate and the drying shrinkage might have not increased significantly if the mid-quality recycled aggregate was used.

3.4. Evaluation of crack resistance with mock-up test

A mock-up test to confirm crack resistance of mid-quality recycled aggregate concrete was performed for walls, as shown in Photo 1, made of recycled aggregate concrete of HMB46 with an expansive agent and of normal aggregate concrete NNP46 (Table 5) for comparison. The total strains at the center of the wall are shown in Fig. 6. It was confirmed that the formation of initial crack of HMB46 specimen was largely delayed compared to the normal aggregate concrete proving an excellent crack resistance of the recycled aggregate concrete.

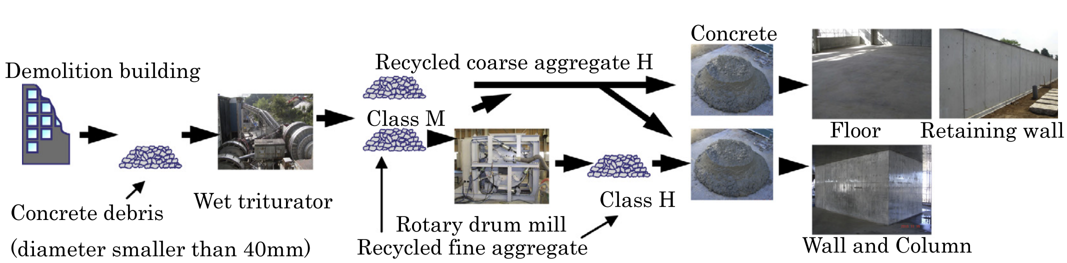

Fig. 1. Recycling system of recycled aggregate concrete.

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