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Improvement of mechanical properties of recycled aggregate concrete basing on a new combination method between recycled aggregate and natural aggregate

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HIGHLIGHTS

- The new combination method between RA and NA in RAC is developed.
- New combination method improves significantly the mechanical properties of RAC.
- Using new method, the amount of recycled concrete aggregate in concrete can raise up 50%.
- The mechanical properties of RAC are affected by RA content following both new and conventional combination methods.

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ABSTRACT

This paper present a new methodology of combination between recycled concrete aggregate (RA) and natural aggregate (NA) in concrete for the purposes of improving the quality of recycled aggregate concrete (RAC) and increasing the amount of RA in RAC. This study investigated mechanical properties of RAC by using new methodology and conventional methodology at different replacement percentages of RA. New methodology enhanced significantly mechanical properties of RAC comparing to conventional method. Using new method for RAC, the amount of RA can be raised up to 50% in concrete while conventional method limited the amount of RA should be less than 30%.

1. Introduction

With the high speed of economic growth, nowadays, most countries have been investing a huge amount of budget into constructing infrastructures, which leads to the fact that the demands of construction materials such as concrete have been increasing significantly. Concrete is the major construction material and plays a crucial role in the improvement of infrastructures such as highways, bridges, buildings etc. It is estimated that the total annual consumption concrete production on over the world is more than 10 billion tons [1]. Besides, natural material for concrete is dwindling sharply due to the exploitation activities of human. Furthermore, the amount of construction and demolition waste (CDW) has been raising considerably in the past decades, because a huge number of building and infrastructures has reached the end of service life, destroyed by natural disasters and wars. It is estimated that about 450 million tons of construction waste is generated every year in EU [2] with only 28% recycled and 72% disposal [3], which has caused environmental pollution and hazard of human's health. Hence, maximizing recycling rate of CDW and popular applicable ability in construction sites are becoming economically important and environmentally necessary [4]. Because natural aggregate sources and the environment are preserved due to reducing a number of mining areas and disposal landfill areas. Additionally, using RA for concrete can reduce fuel consumption for transport and construction cost, while natural aggregate consumes a huge energy at each step of processing. It is estimated that using RA as a replacement of NA in concrete can save up to 60% [5]. Although the researches for use of CDW as recycled aggregates in concrete have been studied for about 50 years, there are few concrete structures using recycled aggregate concrete [6,7]. It is attributed to lack of incentives, low landfill costs, a lack of up-to-date technical regulation [8], lower strength compared to natural concrete [9,10]. As a result, numerous studies have focused on improving the quality of RAC with the purpose to reduce cost and to

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perform friendly environment such as improving properties of RAC by changing the water/cement ratio, adding pozzolanic materials [11]. What is more, recent investigations have tried to enhance mechanical properties of RAC by removing the adhered mortar in RA such as mechanic impacts [12], microwave heating [13], thermal treatment [14], acid solution [15], chemical and thermal treatment [16], ultrasonic cleaning [17] because it is identified that the amount of adhered mortar affected significantly RAC properties [18]. Unfortunately, these methods created unwittingly a new pollutant impacting severely environment. There are also solutions for pre-treating RA proposed in order to rise the bond strength between aggregate and cement paste including impregnating RA with water soluble polymer [19–22], or water repellent polymers [9,23,24], or even an oil-type agent and a silane type agent [25], coating RA with fly ash, silica fume solution [10,17], pozzolanic powder [26]. In addition, the number of researchers suggested solutions to develop strength of adhered mortar as illustrated by carbonating RA [27,28], modifying surface of RA by calcium carbonate biodeposition method [29]; new mixing procedure [30–32]. Nevertheless, these methods increased energy consumption, which leads to raise the cost for producing RAC and creates barriers in applying popularly for the real construction sites. A more simple method for producing concrete containing different percentage of RA was examined in [33,34]. Notwithstanding, the research claimed that the percentage of RA in concrete should be limited less than 30% in order to ensure the quality of concrete because compressive strength of concrete contained less than 30% RA is comparable to that of natural aggregate concrete, which is proven in numerous researches [35–41]. Therefore, the aim of this study is to increase the amount of RA in concrete by proposing a new combination method between NA and RA in RAC as well as improve the mechanical properties of RAC at different levels of replacement. To evaluate the performance of new method, the mechanical properties including compressive strengths, splitting tensile strength, modulus of elasticity and Poisson's ratio are investigated and compared to the conventional method in combining RA and NA in RAC.

2. Materials and experimental program

2.1. Materials

2.1.1. Cement

The cement used in this study is Portland type I cement supplied by Hitachi Company, and is commercially available in Japan. The specific density of the cement is 3.15 g/cm^3 and its chemical properties are shown in Table 1.

2.1.2. Aggregate

Natural coarse aggregates were obtained in the crushed stone quarry (Tokyo Sekkai Kougyo Limited) and have composition as listed in Table 1. The natural coarse aggregates have rough surfaces and angular shapes.

The recycled aggregate derived from CDW of old concrete structures were provided by a local recycling aggregate manufacture plant and crushed by mobile machine. The properties and age of parent concrete of RA are unknown with about 5–10% the amount of impurities such as bricks, tiles, glass and ceramic. The components of RA were detailed in Table 1. The recycled concrete aggregates were sieved and then combined to produce the desired RCA size distribution. The coarse aggregate gradations for both NA and RA were shown in Fig. 1 according to ASTM C33/C33M-13 with 9.5 mm nominal maximum aggregate sizes.

Fine aggregate, crushed from natural stone, has gradation distribution following ASTM C33/C33M-13 as shown in Fig. 2. The finesse modulus of fine aggregate was 2.95 according to ASTM C 136-01. The relative density and absorption of aggregate were determined by ASTM C127-07 for coarse aggregate and ASTM C128-97 for fine aggregates. Weight and moisture content of aggregate were measured according to ASTM C29/C 29M-97 and ASTM C566-respectively.

2.2. A new combination method

Aggregate occupies 70–80% of the volume of concrete [42], and plays an important role in deciding properties of concrete. Coarse aggregate forms the matrix of particles as a main frame bearing the load in concrete structure. The volume of void among coarse aggregate particles is filled up by fine aggregates and cement paste, which affects the density, the amount of cement mortar and performance of concrete. By considering the important role of coarse aggregate in concrete, in this study, the authors proposed a new combination method for RA in concrete. The current aggregate combination method in RAC based on the replacement percentage of the entire of coarse aggregate mixture including all particle sizes in coarse aggregate particles or fine aggregate combined with all particle sizes of NA. Nonetheless, in this new method, the authors replace only large size of RA particle by NA in coarse aggregates. The objectives of this study are to investigate the influence of new combination method on the mechanical properties of RAC and to compare with a conventional combination method between RA and NA with different replacement proportions. Eight different mixtures were mixed with two combination methods (conventional method and new method proposed in this study), and three replacement proportions of RA which is 30%, 50%, and 100% respectively. Eight different condition samples were named as follows:

(1) NAC (100% NA)
(2) RAC (100% RA)
(3) 3N7RN Fig. 3 (30% NA including all aggregates retained over 7.93 mm sieve size and 70% RA including aggregates passed 7.93 mm sieve size complied with new combination method)
(4) 5N7RN Fig. 4 (50% NA including all aggregates retained over 6.73 mm sieve size and 50% RA including aggregates passed 6.73 mm sieve size complied with new combination method)
(5) 7N3RN Fig. 5 (70% NA including all aggregates retained over 5.6 mm sieve size and 30% RA including aggregates passed 5.6 mm sieve size complied with new combination method)
(6) 3N7RO (30% NA and 70% RA complied with conventional combination method)
(7) 5N5RO (50% NA and 50% RA complied with conventional combination method)

Table 1
Chemical compositions of materials (%).

	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Cement	1.07	0.78	3.47	22.63	0.42	62.57	0.23	0.10	3.29
NA	4.39	2.43	16.87	58.40	0.68	7.46	0.97	0.17	10.32
RA	2.69	1.83	12.52	62.56	1.30	12.01	0.62	0.12	5.82