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Combined effects of recycled aggregate and fly ash towards concrete sustainability

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HIGHLIGHTS

- The higher ratio of recycled aggregate resulted in the better flowability of concrete.
- Recycled aggregate concrete with fly ash presented slightly lower yield stress, but much lower plastic viscosity.
- Fly ash caused only a minor reduction in the strength of recycled aggregate concrete.
- Recycled aggregate concrete with fly ash showed much higher chloride resistance than that without fly ash.

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ABSTRACT

The recycling of demolished concrete has been emerging as a sustainable solution to warrant the reduction of construction wastes, as well as to prevent the depletion of natural resources from growing construction demand. Nevertheless, some key factors that would affect the properties of recycled aggregate concrete have not been thoroughly investigated, such as the proportion of recycled aggregates, the moisture state of recycled aggregates, and the design compressive strength of concrete. In particular, little research was done on the combined effects of recycled aggregates and fly ash, popularly used as a partial substitution of cement. Given the concerns, this study investigates the effects of such factors on the mechanical and durability properties of recycled aggregate concrete. Eleven cases of concrete mixtures were tested for the rheological properties of fresh concrete, compressive strength, tensile strength, and chloride diffusion coefficient. In general, the higher ratio of recycled aggregates resulted in the better flowability of concrete. Also, the use of fly ash improved the flowability of recycled aggregate concrete. The strength test results showed that the higher ratio of recycled aggregates generally caused the lower compressive and tensile strengths of concrete. However, the cases with 30% recycled aggregates showed only slight compressive strength reductions. Similarly, the use of fly ash caused only small reductions in the compressive strength of recycled aggregate concrete. In contrast, the negative effects of recycled aggregates and fly ash were greater in the tensile strength than in the compressive strength. Lastly, the cases containing fly ash exhibited much higher resistance to chloride penetration, even in the cases with recycled aggregates.

1. Introduction and background

Climate change, which is often signified by global warming, is one of the most critical global issues that have potential to jeopardize the sustainability of human society. Among many causes, the construction industry is responsible for a major portion of greenhouse gas emission. For example, the production process of cement itself yields approximately 7% of the total CO_2 emission worldwide [1].

Also, construction wastes take nearly 50% of the total solid waste in the US [2], most of which are deposited into landfills that may cause serious environmental pollution problems in both local and global scales. On the other hand, the consumption of aggregates as a construction material has continually increased with universal industrialization and urbanization (e.g., expansion and upgrade of civil infrastructure). Moreover, enhanced legal constraints for the conservation of natural resources have resulted in an imbalance between the demand and supply of aggregates in many countries [3].

To meet the global consensus of sustainable development, technical strategies for ensuring the sustainability of concrete construction have been discussed among the professionals [4–6],

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Nomenclature

f'_c	design compressive strength of concrete (MPa)	T	average of initial and final temperatures in the anolyte solution (K)
τ	shear stress (Pa)	x_d	average chloride penetration depth (m)
τ_0	yield stress (Pa)	t	test duration (s)
μ	plastic viscosity (Pa s)	U	absolute value of the applied voltage (V)
$\dot{\gamma}$	shear strain rate (1/s)	L	thickness of specimen (m)
D	non-steady-state migration coefficient (m^2/s)	erf^{-1}	inverse of error function
z	absolute value of ion valence (=1 for chloride)	c_d	chloride concentration at which the color changes (N)
F	Faraday constant (=9.648 × 10^4 J/V mol)	c_0	chloride concentration in the catholyte solution (N)
R	gas constant (=8.314 J/K mol)		

which suggest saving materials in design, maximizing concrete durability, use of waste or supplementary cementitious materials (e.g., fly ash, and slag), and recycling of concrete. In this study, the last two approaches are investigated: the main objective is to investigate the combined effects of recycled aggregates and fly ash on the mechanical and durability properties of concrete.

The recycling of demolished concrete, which comprises roughly 50% of the total construction waste in South Korea, has been emerging as a sustainable solution to warrant the reduction of construction wastes, as well as to prevent the depletion of natural resources (i.e., stones) from growing construction demand [7,8]. Demolished concrete can be processed into recycled aggregates that may be used as a partial or complete replacement of natural aggregates in concrete production. However, the application of recycled aggregates in concrete products is very limited, because of their inferior qualities to natural aggregates. As shown in Fig. 1 [9], almost 95% of recycled aggregates are used for road embankment, base, pavement, backfill, and such, while applications to concrete products are less than approximately 5% in Korea. Korean Concrete Standard Specifications [10] state that, if the properties and the particle size distribution are satisfied with suggested conditions in Table 3 and Fig. 2, the use of recycled aggregates is allowed within 30% of the total amount of aggregates for concrete products that have the compressive strength of 21–27 MPa.

Recycled aggregate concrete generally shows a lower strength and durability than natural aggregate concrete due to the higher porosity and lower density of recycled aggregates. The Interfacial Transition Zone (ITZ) existing between an aggregate and mortar in concrete is known as a critical factor affecting the overall quality of concrete. Concrete made with recycled aggregates includes old ITZs (between the original virgin aggregates and residual mortar attached to them) as well as new ITZs. This is presumed to be the primary cause of its inferior properties [11].

Nevertheless, some key factors that would affect the qualities of recycled aggregate concrete have not been thoroughly investigated, such as the proportion of recycled aggregates, the moisture state of recycled aggregates, and the design compressive strength of concrete. In particular, little research was done on the combined effects of recycled aggregates and fly ash that is popularly used as a partial substitution of cement. Given the concerns, this study investigates the effects of such factors on the mechanical and durability properties of recycled aggregate concrete: the rheological properties in the plastic state, compressive and tensile strengths, and chloride penetration resistance of concrete. The main objective of this study is to investigate the combined effects of recycled aggregates and fly ash.

Several studies found that the higher ratio of recycled aggregates had a tendency to increase the slump of fresh concrete [12–14]. Also, Siddique [15] tested with changing the substitution ratio of cement by fly ash up to 50%, and reported that the flowability of concrete enhanced with an increased amount of fly ash. During a slump test, the flow of fresh concrete will stop when the shear stress generated by gravity in the concrete is smaller than the yield stress of the concrete. Based on this theory, there has been much research to find out the correlation between slump and yield stress. According to Wallevik [16], several equations were proposed to elucidate the relationship of the two. However, the rheological properties (e.g., yield stress, and plastic viscosity) of recycled aggregate concrete have not been studied much until now, and may not be measured with the conventional slump tests.

Numerous studies investigated the effect of recycled aggregates on the strength of concrete [17–20], and the results generally agreed that the strength decreased when the ratio of recycled

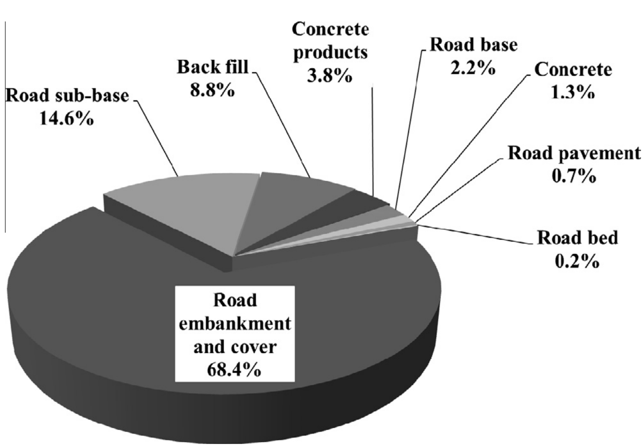

Fig. 1. Usage of recycled aggregates in Korea [9].

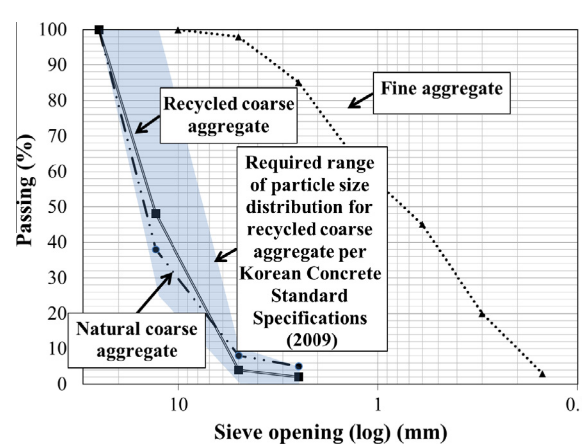

Fig. 2. Particle size distributions of coarse and fine aggregates used in the tests.