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Pore-structures and durability of concrete containing pre-coated fine recycled mixed aggregates using pozzolan and polyvinyl alcohol materials

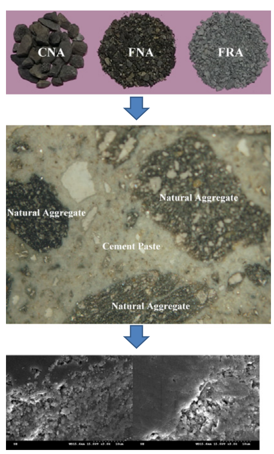
Hsin-Lung Ho [a], Ran Huang [b], Wei-Ting Lin [c,*], An Cheng [c]

[a] Institute of Materials Engineering, National Taiwan Ocean University, Keelung 20224, Taiwan
[b] Dept. of Harbor and River Engineering, National Taiwan Ocean University, Keelung 20224, Taiwan
[c] Dept. of Civil Engineering, National Ilan University, Ilan 26047, Taiwan

HIGHLIGHTS

- This is a recycled cementitious material.
- Cementitious was mixed pre-coated fine recycled aggregates.
- Pore-structures of the recycled materials was approximately traditional concrete.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, we coated fine recycled concrete aggregate (FRCA) with fly ash, slag, or polyvinyl alcohol (PVA) (viscosity: 44–50 cps), replaced 25% of the natural fine aggregate in concrete with the coated FRCA, and examined the durability and microscopic properties of the flesh concrete and hardened concrete. We then examined the effects of the various types of coating as well as the thickness on the properties of concrete.

Our test results indicate that coating FRCA with fly ash or PVA increases the workability of the fresh concrete, whereas slag coatings slightly reduce the workability. Slag coatings increased the compressive strength, splitting strength, and durability of specimens to a greater degree than do fly ash or PVA coatings, regardless of the water-cement ratio. Furthermore, thicker coatings were shown to produce better results. Scanning electron microscopy images and mercury intrusion porosimetry tests verified that specimens containing FRCA coated with slag resulted in superior engineering properties.

Abbreviations: CH, calcium hydroxide; CRCA, coarse recycled concrete aggregate; C-S-H, calcium silicate hydrate; FRCA, fine recycled concrete aggregate; ISAT, initial surface absorption; ITZ, interfacial transition zone; NFA, natural fine aggregate; NCA, natural coarse aggregate; PVA, polyvinyl alcohol; RCA, recycled concrete aggregate; SEM, scanning electron microscopy; SSD, saturated surface dry.

* Corresponding author.
E-mail address: wtlin@niu.edu.tw (W.-T. Lin).

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1. Introduction

Rapid urbanization has led to a significant increase in the quantities of construction waste, most of which is not utilized to the fullest and therefore poses a threat to the environment. In Taiwan, the Construction and Planning Agency of the Ministry of the Interior oversees the management of construction waste. In May of 1991, they promulgated the Management Guidelines for the Disposal of Construction Surplus, in which surplus construction materials (such as the mud, soil, sand, stone, brick, and concrete blocks remaining from building construction, public works, and other civil works) are designated as reusable resources. In 2010, the Management Measures for the Reuse of Construction Waste in Taiwan was proclaimed to promote the recycling of construction waste [1]. In October of 2006, the Architecture and Building Research Institute of the Ministry of the Interior solicited the help of Professor Ta-Peng Chang to draft construction specifications for recycled concrete. With Professor Ran Huang as the convener, a team of domestic experts was organized to validate the draft and publish a manual for the recycling of concrete [2].

Recycled aggregate comprises natural aggregate with cement mortar adhered to its surfaces (Fig. 1), which results in lower density, greater porosity, higher water absorption, and higher wear [3,4]. These effects can compromise strain resistance (flexibility, shrinkage, and creeping), mechanical properties (compressive strength), and durability. The process by which the material is crushed influences the amount of cement mortar that remains adhered to the surfaces of the aggregate. Some crushing processes remove more of the adhered cement mortar and thereby enhance the quality of the resulting aggregate.

In most concrete casting processes, the lower density of water causes it to rise in the mixture and accumulate on the surface above the aggregate. The resulting film of water creates an interfacial transition zone (ITZ), as shown in Fig. 1. Structurally speaking, ITZs are weak planes in which the mixture is loose and porous. Even when only 20–40 μm in thickness, ITZs affect the mechanical properties and durability of concrete. The same is true in recycled concrete. ITZs is the result of uneven movement between aggregate and hydrated cement mortar, resulting in the formation of ruptures. The pores and microcracks within ITZs can have a considerable impact on concrete quality [5,6]. These problems can be overcome by including a suitable admixture in the concrete. Common admixtures include pozzolanic materials (such as silica fume, slag, and fly ash) and fibers (such as glass fiber, carbon fiber, and steel fiber). Pozzolanic reactions help to fill in pores and make the concrete denser, whereas fibers enhance the mechanical properties of the concrete, such as resistance to shearing forces and bending moments [7–11].

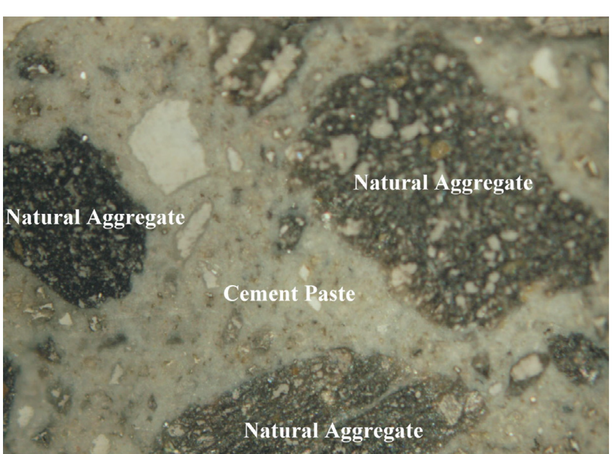

Fig. 1. Recycled aggregate comprises natural aggregate with cement mortar adhered to its surfaces.

Recycled concrete aggregate (RCA) is produced from crushed waste concrete. The product is screened, graded, and then mixed in specific proportions to create recycled concrete [12]. The waste concrete used to make RCA can contain waste concrete gravel, broken brick, roof tiles, glass, ceramics, slag, mineral waste, and gypsum as well as waste plastic, waste rubber, tire rubber, wood, waste paper, and other impurities [13–15]. Waste concrete gravel generally accounts for the largest proportion. The low compressive strength of brick greatly reduces the overall compressive strength of recycled concrete. Waste concrete gravel is a combination of natural aggregate and old cement mortar. The surface is rough and porous. It is not as well-shaped as natural aggregate; however, it meets the particle shape requirements of concrete aggregate. Cement mortar adhered to the aggregate surfaces can have a significant impact on the properties of the recycled concrete [16,17]. Researchers have sought to replace some of the fine aggregate in concrete components with particulate plastics, glass, and glass fiber. Mechanical tests have been used to examine, elasticity, compressive strength, splitting, and tensile strength, and the relationships between their microstructures and fracture interfaces have been analyzed using scanning electron microscopy (SEM). Crushed and graded waste concrete aggregate is not the only source of RCA; however, it is the most common in current research and application. Using RCA as concrete filler, the grading, shape, specific gravity, waster absorption rate, and variations in water content must be observed, as they can alter the properties of the recycled concrete [17,18].

Recycled waste and aggregate can be used as backfill in road works as well as in structural concrete; however, it is still not widely used by the public. This can be attributed to the fact that the quality of RCA does not match that of natural aggregate. Researchers [19,20] have reported on the water absorption of RCA: particles 16–32 mm in diameter (3.7%) and, 4–8 mm in diameter (8.7%). Research [21,22] on the unit weight of coarse recycled concrete aggregate (CRCA) crushed from large batches of waste concrete has revealed that the unit weight of CRCA with a saturated surface dry (SSD) specific gravity of 2.29–2.51 ranges from 1120 kgf/m^3 to 1430 kgf/m^3 whereas the SSD specific gravity of the fine recycled concrete aggregate (FRCA) ranges from 2.29 to 2.51. RCA has lower specific gravity than does natural aggregate because it contains cement mortar, which has a lower specific gravity [23].

According to the literature [24–26], the density of RCA is 10% lower than that of natural aggregate. The water absorption of CRCA is 3.5–9.0%, whereas that of FRCA is between 5.5% and 13%. This far exceeds the 0.5–1.0% of natural aggregate. Furthermore, the wear resistance of RCA (based on the Los Angeles test) is 70% that of natural aggregate. Previous research [12,13,26] has indicated that RCA made from crushed concrete has a lower specific gravity than does natural aggregate. The SSD bulk specific gravity of CRCA in Taiwan falls between 2.26 and 2.43, whereas the SSD bulk specific gravity of FRCA falls between 2.27 and 2.29. The water absorption of CRCA in Taiwan is 5.04–7.52%, whereas the water absorption of FRCA is 7.92–10.37%. In contrast, the water absorption rate of natural aggregate is only 0.8–3.7%. Thus, it is generally recommended that RCA undergo pre-wetting (to SSD state) before being mixed into recycled concrete in order to preserve the quality of the resulting recycled concrete.

RCA is commonly coated with mortar containing many fine cracks, which increase the porosity of RCA and reduce the apparent density. When the apparent density is equal to or less than 2250 kN/m^3, it is no longer suitable for recycled concrete. A number of