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Mechanical strength and drying shrinkage properties of RCA concretes produced from old railway concrete sleepers using by a modified EMV method

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HIGHLIGHTS

- PC sleepers with maximum size of 20 mm aggregate were crushed into 25 mm RCAs.
- Modulus of elasticity of RCA concrete with modified EMV mix is comparable to that made with natural aggregate concrete.
- RCA concrete by modified EMV mix retains lower drying shrinkage strain, compared to the companion natural aggregate concrete.
- Use of coarse RCA produced from old PC sleepers is promising for structural concrete.

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ABSTRACT

This study aims to assess the mechanical strength and shrinkage properties of recycled concrete aggregate (RCA) concretes produced from old railway pre-stressed concrete (PC) sleepers. PC sleepers with compressive strength of 50 MPa grade, originally manufactured with a maximum size of 20 mm coarse aggregate, were crushed into 25 mm RCAs. A total of six mixes were prepared for typical structural concrete, using the modified equivalent mortar volume (EMV) as well as the conventional ACI mix design method. Comparable values of the elastic modulus and drying shrinkage properties of RCA concrete were achieved from the test results, relative to those of the companion natural aggregate concrete. The use of RCA produced from old PC sleepers is thus proven to be promising when RCA production is targeted for coarse aggregate in structural concrete.

1. Introduction

Most of the studies agree that RCA is more heterogeneous, porous and less dense than natural aggregate. The main properties unfavorably affected by the attached residual mortar are density, absorption, porosity and abrasion [1]. Especially adhered residual mortar (RM) in RCA leads to higher porosity and hence higher water absorption for RCAs [2], and the porosity was represented by water absorption [3]. Generally, lower RCA strength source showed higher porosity of the aggregate itself and the newest interfacial transition zone (ITZ). Some studies on the RCA indicated the weaker interfacial transition zone (ITZ) between the cement paste and the RCA [4,5]. Kaltz [6] introduced pre-treating RCA and its weaker ITZ with silica fume solution, and increase of 15–30% in compressive strengths was observed. However, it was pointed out that the pre-treating process will lead to a higher cost [7]. Also thickness of the RM is an important factor which affects physical properties of RCA concrete. However, it is reported by Leite and Monteiro [5] that the thickness of the ITZ in RCA concrete is in the same order of magnitude, varying from 30 to 50 µm as the natural aggregate concrete. Further research may be needed in this research area.

In general, the concrete quality of recycled concrete aggregate (RCA) obtained from highway or airbase reconstruction job-sites is superior to that from demolition waste recycling plants [8]. This may be ascribed to the high quality of the original virgin aggregate of the RCA and the small amount of foreign substances, which are often seen in plant RCAs, such as bricks, asphalt, etc [8]. Thus, it can be expected that the RCA manufactured from wastes of precast structural concrete is clean and of high quality [9,10]. It is stated in the Spanish standard [11] that RCA concrete obtained from healthy precast structural concrete could be suitable for structural reinforced concrete with compressive strengths higher than

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40 MPa, but allowing maximum 20% replacement of coarse aggregate by RCA. It was stated by several researchers [12–14] that properties of original concrete have significant influences on mechanical properties of recycled aggregate concrete. Their results indicated that the compressive strength of the high performance RCA concretes prepared with RCA derived from over 80 MPa precast structures was similar or slightly higher than that of natural aggregate concrete. Moreover, the concrete mixtures made with RCA which were derived from parent concrete with higher strength had lower drying shrinkage.

A great deal of effort has recently been put into reusing old concrete sleepers [15–19], which can be considered for use in precast products. In some cases, degraded concrete sleepers have been freely used as retaining walls and outdoor garden stairs. Since 2008 in South Korea, the recycling of creosote-treated timber sleepers has been a major issue. Researchers [20,21] reported that creosote, which contains high quantities of polycyclic aromatic hydrocarbons (PAHs), could cause skin irritation and disease. All creosote-treated timber sleepers were considered hazardous wastes and prohibited from being reused in garden stairs [21]. Old concrete sleepers have since been mistakenly designated as hazardous waste materials. Furthermore, old concrete sleepers left in vacant lots around railroads for a long time are a great concern due to environmental pollution near railroad areas. Roughly 200,000 old concrete sleepers which are mostly replaced in Korail national line are released every year, and recycling is demanded. The total length of Korail national line is 9364 km, and that of sub-urban railway in metropolitan city area is 1415 km. This is about 1.4% replacement of the PC sleepers in the Korail national line. However, no reasonable plan for recycling has been suggested thus far, because old concrete sleepers are designated as environmental waste.

An ideal way of obtaining high quality RCAs is acquiring them from concrete railway sleepers. One of the main advantages of obtaining RCAs from concrete sleepers is reduced sorting costs and obtaining reliable products. Material properties of high performance RCA concrete (RAC) railway sleepers were investigated and compared to those of conventional concrete by Gonzalez-Corominas and Etxeberria [15]. Test results showed that concrete made with 50% of coarse mixed aggregate had adequate durability properties [15]. Sustainable concrete mix designs for sleepers were proposed by Barbosa et al. [16] and Prosek et al. [17] and RCA mixtures with crushed marble waste sand with the addition of fibers resulted in excellent mechanical and durability properties. The structural behavior of pre-stressed concrete sleepers was evaluated by Gonzalez-Corominas et al. [18]. Two types of high performance recycled aggregate concrete (HPRAC) were presented in their study, using 50% and 100% RCA in replacement of coarse natural aggregates. The experimental results showed satisfactory performance of HPRAC sleepers, being very similar to that of the control HPC sleepers. Another study, aimed at improving the mechanical strength properties of polymer concrete, was carried out by Carrion et al. [19] using waste fine aggregates collected from the recycling process of concrete sleepers. It was noted that the recycled fine aggregates (basalt and limestone) were evaluated as an excellent and suitable source for high-quality by-products. Meanwhile, Han and Thakur [22] showed that concrete railway structures made from recycled ballast, which had been used and degraded progressively under repeated loading as a load-bearing material, improved excessive deformation when reinforced with geosynthetics.

However, unless a limited amount of fine fractions of RCA is used with fiber or polymer resins, the mechanical strength properties of RCA concrete are not improved, regardless of the quality of RCA manufactured from old HPC sleepers. It is known that, in general, the compressive strength of RAC is decreased due to changes in the mortar strength and the aggregate-mortar bond strength at the interfacial transition zone [23–25]. The modulus of elasticity and drying shrinkage are also decreased due to changes in the volume of the mortar [23–25]. To overcome these problems, equivalent mortar volume (EVM) mix design methods were proposed by Fathifazl [23] and his colleagues [24,25]. According to these theories, in fresh concrete before hardening, residual mortar (RM) acts as a coarse aggregate and RM acts as mortar, after hardening [23–25].

Fig. 1 illustrates the concepts of various mix designs including the conventional ACI mix design and modified equivalent mortar volume (EMV) mix design. The unique feature of the EMV method is the treatment of residual mortar (RM) in RCA as part of the total mortar (TM) content of RCA concrete. By the conventional mix design, the TM volume in RCA concrete (Fig. 1b) is larger than the TM volume of natural aggregate (NA) concrete (Fig. 1a). It should be noted in Fig. 1b that RCA is composed of RM and original virgin aggregate (OVA) as total coarse aggregate (TCA). Thus, the conventional RCA concrete mix design causes an increase in the TM volume, which subsequently affects the modulus of elasticity and drying shrinkage properties.

In the modified EMV model, the residual mortar (RM) attached to RCA serves as aggregate in fresh concrete, and as mortar after it is hardened. Considering this treatment, the RM volume in RCA concrete is represented by the sum of the volume fraction of mortar (RM_a) and the other volume fraction of aggregate (RM_b).

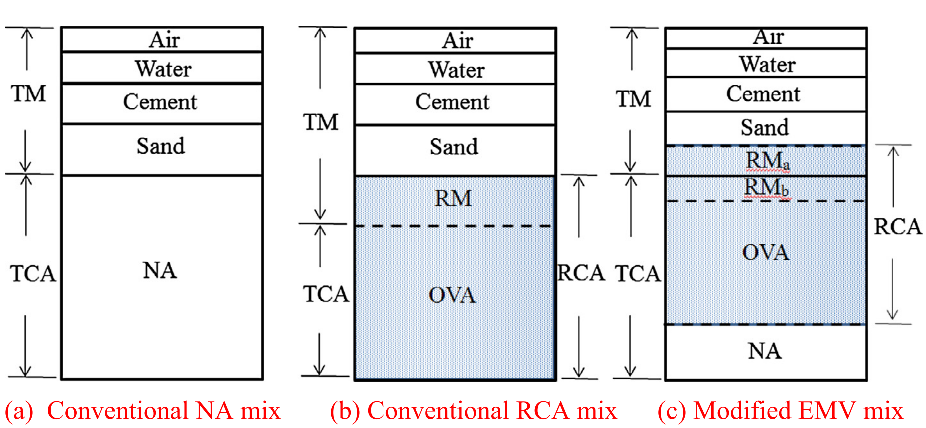

Fig. 1. Comparison of various mix design concepts [8,26].