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Case study

Sustainable normal and high strength recycled aggregate concretes using crushed tested cylinders as coarse aggregates

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ABSTRACT

The paper reports on a research program that was designed at the American University of Beirut (AUB) to investigate the fresh and hardened mechanical properties of a high performance concrete mix produced with partial or full substitution of crushed natural lime-stone aggregates with recycled aggregates from crushed tested cylinders in batching plants. Choosing crushed cylinders as source of recycling would result in reusing portion of the waste products of the concrete production industry. An extensive concrete batching and testing program was conducted to achieve two optimum normal and high strength concrete mixes. The variables were the nominal concrete strength (28 or 60 MPa) and the percentage replacement of natural coarse aggregates with recycled aggregates from crushed tested cylinders (0, 20, 40, 60, 80, or 100%). Normal strength tested cylinders were used as source of the recycled aggregates for the normal strength concrete (NSC) mix and high strength tested cylinders were used for the high strength concrete (HSC) mix. Tests on the trial batches included plastic state slump and hardened state mechanical properties including cylinder compressive strength, cylinder splitting tensile strength, modulus of elasticity, and standard beams flexural strength. The results indicated no significant effect on the slump and around 10% average reduction in the hardened mechanical properties for both investigated levels of concrete compressive strength.

1. Introduction and previous research

The production of construction waste material has been increasing worldwide at a large pace. This is due to the big boost in construction activities that led to the demolition of a big number of existing old buildings either because of the limited land for new development or due to the fact that existing buildings are structurally defected. Another source of construction waste comes from the concrete production procedure itself which includes sampling standard concrete cylinders in significant numbers for each cubic meter of concrete produced. The tested concrete cylinders represent a good portion of the dumped construction waste material. The accumulation of such demolition waste has had detrimental impact on the environment if there is lack of plans and methods to manage, handle, and dispose dismantled waste properly.

Conventional concrete which is the most widely used construction material worldwide has been claimed not to be environmentally friendly. Negative concerns include the depletion of natural resources, high energy consumption, and construction waste disposal. Therefore, recycled aggregate concrete (RAC) would help the preservation of natural resources, alleviation of construction waste disposal problem with its negative environmental impact, and production of a sustainable and green concrete

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material.

According to a study by the Federal Highway Association (FHWA) in 2004, thirty eight American states recycle concrete as an aggregate base and eleven states incorporate recycled aggregates into newly produced concrete. The states that use RAC report that this concrete equally performs as concrete prepared with natural aggregates.

According to the ACI Committee 555 report [1], the process of recycling concrete involves producing a material with a specified size and quality by breaking, removing, and crushing existing concrete. The quality of recycled aggregate concrete relies mostly on the quality of the processed existing concrete. All non-concrete material including reinforcement steel and any embedded material must be removed. Also, materials that can negatively affect the strength of RAC must be detected and removed to prevent contamination of the end product with troublesome material like chlorides, soil balls, clay balls, asphalt and other similarly harmful material. Moreover, according to the ACI Committee 555 [1], RAC with similar consistency and workability as conventional natural aggregate concrete (NAC) made with natural materials would require 5% additional water and in other cases even 15% additional water was required for RAC. The bleeding from RAC was found to be slightly less than that of conventional concrete using natural aggregates. Recycled aggregates generally have densities slightly less than the original materials used. One main difference between recycled aggregates and natural aggregates is the higher water absorption due to the presence of old cement mortar adhered to the recycled aggregate particles. Recycled coarse aggregates are expected to exceed ASTM requirements for the Los Angeles Abrasion test. The compressive strength of RAC depends on the strength of the original concrete and is largely influenced by the water-cement ratios (w/c) of the original and the recycled concretes. The majority of researchers found that the compressive strength for concrete manufactured from recycled coarse and fine aggregates was lower than that of concrete made with all naturally occurring materials by 15–40%.

Many papers are reported in the literature on research conducted on the mechanical properties and durability aspects of RAC. In 2000, Nagataki et al. reported on a study investigating the effect of several physical properties of recycled aggregates including the structure and amount of adhered mortar on the performance of recycled aggregate concrete [2]. The results indicated that all possible variations in the recycled aggregate properties should be taken into account in designing durable recycled aggregate concretes.

Shayan and Xu evaluated techniques to improve the surface properties of recycled concrete aggregates and establish the influence of the improved RCA on the strength development and durability properties of concrete with nominal compressive strength of 50 MPa [3]. The durability properties included drying shrinkage, alkali-aggregate reaction (AAR), sulfate resistance, and chloride permeability. Test results indicated similar durability aspects of recycled concrete aggregates and natural aggregates.

In 2007, Rahal reported the results of a comparative experimental study of several mechanical properties of recycled and natural aggregate concretes made with the same mix proportions to achieve a nominal concrete strength between 25 and 30 MPa [4]. The study examined the development of cube compressive strength and the indirect shear strength at five different ages: 1, 3, 7, 14, 28 and 56 days; the strains at maximum compressive stress; and the modulus of elasticity tested by using standard 15 × 30 cm (6 × 12 in.) concrete cylinders at 28 days. Rahal concluded that at 28 days, the cube and cylinder compressive strength and the indirect shear strength of RAC were on the average 10% less than those of NAC. The reduction in the modulus of elasticity was only 3%. Similar trends between RAC and NAC were observed in the development of compressive and shear strength and the strain at peak stress.

Etxeberria et al. investigated RAC produced using four different percentage replacements of natural aggregates with recycled coarse aggregates used in the wet unsaturated condition: 0, 25, 50 and 100% [5]. Results indicated lower modulus of elasticity values when recycled coarse aggregates were used.

In another study reported in 2007 by Rao et al., a brief overview of the properties of recycled aggregates sourced from construction and demolition waste was presented along with the effect of introducing recycled aggregates in concrete mixes on the fresh and hardened concrete properties [6]. The main factors negatively affecting the use of RAC in the industry were identified including lack of codes and specifications and absence of government support.

Yang et al. studied the influence of the type and percentage replacement of NCA with RCA on concrete properties [7]. Test results showed that the fresh and hardened properties of concrete containing recycled aggregates were dependent on the relative water absorption of aggregates. In addition, the modulus of rupture and modulus of elasticity of RAC were lower than the design equations specified in ACI Building Code [8] when the relative water absorption of aggregates was above 2.5% and 3.0%, respectively.

Recently in 2012, S. F. U. Ahmed reported the effect of introducing recycled aggregates originating from construction and demolition wastes in West Australia on the properties of concrete [9]. The percentage replacements by weight of natural coarse aggregates with recycled aggregates were 25, 50, 75 and 100%. Also, the effect of replacing 40% of the cement with Class F fly ash on the properties of RAC was studied. The tested properties included compressive strength, indirect tensile strength, flexural strength, and water absorption. The results indicated increase in the mechanical properties of concrete made with 25% replacement recycled aggregates. RAC containing 40% replacement of cement with fly ash had greater compressive strength at old ages and lower indirect tensile and flexural strengths at all ages. Moreover, the water absorption decreased as recycled coarse aggregate content increased and decreased even more significantly when fly ash was introduced.

2. Objectives and research significance

The sustainable advantages of RAC and the need to mitigate the negative environmental impact of the construction waste material resulting from crushed tested cylinders in the concrete industry prompted the initiation of a research program at the American University of Beirut. The objective of the research reported in this paper was to perform different trial concrete batches to achieve optimum normal and high strength concrete mixes which fit the criteria of RAC as far as workability and performance. The main