Construction and Building Materials 185 (2018) 310–324

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Improving the shear performance of reinforced concrete beams made of recycled coarse aggregate

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HIGHLIGHTS

- The shear capacity of RC made of recycled coarse aggregate was studied experimentally.
- The effect of the replacement ratio of the recycled aggregate has been investigated.
- Compensating the lost capacity was restored by providing internal short fibers.
- Curing the recycled aggregate enabled the RC beams made of recycled aggregate to be enhanced.

ARTICLE INFO

Article history:
Received 12 April 2018
Received in revised form 9 July 2018
Accepted 11 July 2018

Keywords:
Recycled coarse aggregate
Shear strength
Curing methods
Polypropylene fiber
Shear design
Codes and standard

ABSTRACT

This paper investigates experimentally and analytically the shear performance of RC beams made of recycled coarse aggregate (RCA). Previous studies showed that the partial replacement of the virgin coarse aggregate by recycled one results in decrease the shear strength of RC beams. Consequently, the main target of the this research was to compensate such decrease in the shear strength by providing internal short fibers and using cured recycled coarse aggregate instead of crude recycled coarse aggregate. A total of eleven simply supported RC beams made of recycled coarse aggregate along with one conventional concrete beam were tested under incremental four-point loading scheme. The considered parameters were the recycled coarse aggregate replacement ratio (15, 30 and 45%), the shear span-to-depth ratio (1, 2 and 3) and the fiber volumetric ratio (1, 1.5 and 2%). In addition, to improve the physical and mechanical properties of the recycled coarse aggregate (RCA), two curing methods for the RCA were implemented using cement slurry and Styrene Butadiene Rubber (SBR) compound. The experimental results showed that increasing the replacement ratio of the RCA resulted in decrease the shear capacity proportionally. The percentages of decreases in the shear capacities were about 8%, 14% and 19%, respectively, for RC beams provided by RCA replaced by 15%, 30% and 45%. In addition, it was shown that providing internal short fibers by volumetric ratios of 1%, 1.5% and 2% enabled the RC beams made of 30% partial replacement of the recycled coarse aggregate to compensate the decreases in the shear capacities (14%) and to increase their shear capacities by about 13%, 15% and 22% compared to those of the control beam, respectively. Furthermore, for RC beams made of 30% partial replacement of the RCA, the shear capacities decreased by about 2%, 14% and 37%, respectively, for beams having shear span-to-depth ratio of 1, 2 and 3. Besides, it was shown that, the cured recycled coarse aggregate enabled the RC beams made of 30% partial replacement to exhibit improved shear performance. However, the curing method based on cement slurry showed higher improvement since the restored shear capacities were about 15% and 3% for beams provided by cured coarse aggregate based on cement slurry and compound SBR, respectively compared to that of the beam made of crude RCA. Finally, an equation for estimating the shear capacity of RC beams made of recycled coarse aggregate was proposed and it showed satisfactory results when verified against the experimental findings of the current research as well as of other researches where the maximum variations were about 8.5% and 22%, respectively.

1. Introduction

Currently, the amount of demolition wastes resulting from concrete buildings due to the expired life time of the buildings and/or

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https://doi.org/10.1016/j.conbuildmat.2018.07.065
0950-0618/

the terrorism attack and recent wars are becoming an environmental problem. Thus, recycling of concrete waste represents a new way to get rid of such demolition waste as well as to find out a new resource for the concrete production. It is well recognized that the main component of the concrete is the coarse aggregate, which represents about 60% to 75% of concrete volume. Coarse aggregate is mainly obtained by blasting rock blocks and then by crushing them to the required size. This process is detrimental for the environment where it destroys mountains, erodes the soils, and produces huge quantities of Carbon Dioxide. Thus, using of recycled aggregate has many benefits such as economic aspects, preserving the consumption of limited resources and decreasing the environmental pollution. Generally, recycled coarse aggregate produced by crushing, screening and removing the impurities from the demolition waste [1]. In contrast, the rate of consumption of natural aggregate is rapidly increasing due to the production and utilization of concrete. Recycled aggregate could treat this problem by converting the waste product to a new resource for the coarse aggregate.

Cement paste and some amount of mortar from the original concrete remain attached to stone particles of recycled coarse aggregate. Consequently, the recycled coarse aggregate has lower density, higher porosity, and higher water absorption capability than those of the natural aggregate. Therefore, it is very essential to use the suitable curing or treatment techniques in order to maintain the moisture and temperature condition for the surface of the recycled coarse aggregate. Hydration using calcium aluminate hydrates or calcium silicate hydrate also known as cement gel is one type of recycled aggregate curing. Hydration reactions are continued until all the cement reaches its maximum degree of hydration or until the cement gel fills all the available space, whichever limit is reached first. As the hydration reactions proceed, the water-filled space in cement paste is increasingly replaced with solid hydration product, which results in increasing its strength and decreasing its permeability. Due to its nanoscale pore system and high water content, the calcium silicate hydrate gel is the primary phase affected by drying of cement paste. Thus, calcium silicate hydrate compound affect concrete hardening, while calcium aluminate hydrates compounds control the workability [2].

Water curing and steam curing [3] are other curing methods. Katz [4] treated the recycled aggregate by impregnation of the recycled coarse aggregate in silica fume solution and cleaning the recycled aggregate by ultrasonic. Results showed that impregnation of recycled aggregate in silica fume led to an increase of about 15 to 30% in the concrete compression strength at ages 7 to 28 days.

Some researchers investigated the use of chemical components to treat the recycled aggregate such as calcium metasilicate (CM), Nano silicate (NS), and HCL acid [5–7]. It was found that the RCA impregnated in calcium metasilicate (CM) solution resulted in better concrete strength than the RCA treated by Nano silicate (NS) In addition; the recommended optimum concentration of CM solution for treated coarse RCA was about 10% [5]. In addition, the surface treatment by presoaking the RCA in HCL acid at 0.1 M concentration effectively removed the loose mortar particles and thereby significantly improved the properties of the RCA [6]. Furthermore, the results showed that the behavior of RCA had improved with reduction in water absorption, without simultaneous exceeding the limits of chloride and sulphate compositions after the pre-soaking treatment approaches based on HCl, H_2SO_4 and H_3PO_4 [7].

Other researchers studied coating the recycled aggregate by cementitious and powder components such as cement slurry, Stone Envelope Pozzolanic Powder (SEPP), and Polyvinyl alcohol powder (PVA) [8,9]. It was found that the slump and strength results indicated that the new mixing technique of RCA based on stone enveloped with pozzolanic powder (SEPP) contributed significantly to better workability and higher compressive and flexural strengths. In addition, the interfacial transition zone was noticed to be denser than those patches prepared by normal mixing approach (NMA) or stone enveloped with Portland cement (SEPC) approach [8]. Furthermore, the test results showed that there was not only an improvement in the mechanical properties of the concrete made with PVA impregnated RCA, but also the shrinkage was noticed to be decreased [9].

The shear force in reinforced concrete beams is transferred through the concrete compression zone, the dowel action of flexural reinforcement, the aggregate interlock between the aggregate particles, and the transverse shear reinforcement. Whereas, the aggregate interlock defined as the interface transfer of shear force between the rough concrete crack faces. The efficiency of shear transfer through aggregate interlock is reduced if the coarse aggregate fractures at cracks [10]. Thus, the use of recycled coarse aggregate in structural RC member could lead to an adverse effect on the shear strength. As a consequent, many researchers devoted their effort to study the shear behavior of recycled aggregate RC beams. Whereas, they focused on the following parameters: recycled aggregate replacement ratio RCA% [11–22], longitudinal reinforcement ratio ρ%[11,21,23-25], shear span-to-depth ratio a/d [14,16-24,26,27] size effect [13,17,25,26], the amount of shear reinforcement [16,18,19,25], concrete compressive strength [20,22] and treatment method [25,26].

The majority of experimental test results conducted on the shear behavior of RC beams made of recycled coarse aggregate reach the same findings that could be summarized as follows:

- The shear strength declines with increasing the recycled aggregate replacement ratio [11-22].
- The shear strength decreases as the shear span-to-depth ratio increased while other parameters are held constant [14,16–24,26,27].
- Using treated recycled coarse aggregate increased the compressive and shear strengths compared to concrete made of untreated recycled aggregate [3–9,25,26].
- The crack pattern of recycled aggregate concrete beams and failure mode are alike to those of conventional concrete beams [11-14,22].
- Cracks widths of recycled aggregate concrete beams are wider than those of control beam due to weak aggregate interlock of recycled aggregate [8,20,21].
- Both conventional concrete and recycled aggregate concrete beams that provided with large percentage of transverse reinforcement do not produce any diagonal tension cracks [16,18,19,25].
- The evolution of shear cracks is severe in concrete with higher recycled aggregate replacement ratio and less longitudinal reinforcement ratio [11,21,23–25].
- The shear strength of recycled aggregate concrete beams decreased with increasing the effective depth regardless of replacement ratio [13,17,25,26].

In the current study, the shear performance of RC beams made of recycled coarse aggregate provided by 15%, 30% and 45% replacement ratio of the virgin coarse aggregate has been studied experimentally. Besides, in order to improve the aggregate interlock between the recycled coarse aggregate, polypropylene short fibers were provided with different volumetric ratios; namely, 1%, 1.5% and 2%. Furthermore, two curing techniques based on cement slurry and Styrene Butadiene Rubber (SBR) compound were implemented in order to enhance both physical and mechanical properties of the used recycled coarse aggregate.