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Partially hydrated recycled aggregate concrete: A systematic approach towards sustainable development

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HIGHLIGHTS

- Use of PHRCA along with PP fiber produces a sustainable and cost effective concrete.
- Addition of PP fiber improves the mechanical properties of both NAC and PHRAC.
- The bond strength remains unaffected even at 100% use of PHRCA.
- *t*-Test confirms, compressive strength and bond strength are unaffected by PHRCA.
- The addition of 0.6% of PP fiber content by weight of cement is recommended.

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ABSTRACT

The experimental investigation on the mechanical properties of partially hydrated recycled aggregate concrete (PHRAC) with the addition of polypropylene fiber (PP fiber) is carried out and compared with the conventional concrete. The 28 days compressive strength is observed to be higher for PHRAC, whereas the tensile strength is lower than natural aggregate concrete (NAC). Based on the mechanical properties, the optimal dosage of PP fiber for both NAC and PHRAC is obtained as 0.6% by weight of cement. The bond strength is also evaluated by conducting the pullout tests using rebar of 12 mm, 16 mm and 20 mm diameter. Higher bond strength is experienced for PHRAC with respect to NAC, whereas the PP fiber addition does not have a significant effect on the bond strength of concrete. Further, *t*-test reveals that, barring flexural tensile strength other mechanical parameters are not influenced either by the type of aggregate or by the incorporation of PP fiber. The cost analysis shows that, the preparation of PHRAC is 4.5% cheaper than NAC.

1. Introduction

The increasing demand of the construction work across the globe develops the situation of scarcity of qualified natural building materials. In addition to this, generation of huge quantity of construction and demolition (C&D) waste is also associated with the activities related to the infrastructure development. Further, the institutions and construction related research sectors are the continuous source of this C&D waste, which is generated after the testing of concrete specimens (cube, cylinder, beam, column, slab, precast specimens etc.) in the laboratory. Usually this C&D waste is used for land filling. However, due to the generation of huge quantity of C&D waste, the disposal of this waste is one of the major problem all over the world. Hence, instead of using this C&D waste for land fill, the utilization of the same as a potential substitution of natural aggregate is a wise alternative. It will not only solve the problem of land filling but also reduce the burden on environment. In this aspect, the waste concrete present in the C&D waste can be utilized to extract aggregate. Thus, the recycling of the laboratory tested specimens to extract aggregate for concrete production will impart a huge positivity in the field of sustainability.

The research on recycled aggregate concrete (RAC) is being accelerated over the past several years, in order to come up with possible replacement for natural coarse aggregates (NCA). In this context, the recycled aggregate has been successfully implemented in road construction [1–3] and geotechnical applications [4]. However, the utilization of recycled coarse aggregate (RCA) in structural applications is not frequent for the reason of having inferior quality of concrete produced using RCA than that of conventional concrete

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Nomenclature

NCA	Natural coarse aggregate
NAC	Natural aggregate concrete
NACF	Natural aggregate concrete with PP fiber
PHRCA	Partially hydrated recycled coarse aggregate
PHRAC	Partially hydrated recycled aggregate concrete
PHRACF	Partially hydrated recycled aggregate concrete with PP fiber
PP fiber	Polypropylene fiber
F0, F0.3, F0.6, F0.9 and F1.2	Concrete with PP fiber percentage of 0%, 0.3%, 0.6%, 0.9% and 1.2%, respectively
N12, N16 and N20	Bond strength test specimens of NAC with rebar diameter of 12 mm, 16 mm and 20 mm, respectively
N12F, N16F and N20F	Bond strength test specimens of PP fiber reinforced NAC with rebar diameter of 12 mm, 16 mm and 20 mm, respectively
R12, R16 and R20	Bond strength test specimens of PHRAC with rebar diameter of 12 mm, 16 mm and 20 mm, respectively
R12F, R16F and R20F	Bond strength test specimens of PP fiber reinforced PHRAC with rebar diameter of 12 mm, 16 mm and 20 mm, respectively
INR	Indian rupee (currency of India)

[5]. The instructions for the use of recycled aggregates by RILEM TC 121-DRG [6] categorised them into different groups viz., aggregates which are extracted from masonry rubble, aggregates obtained from concrete rubble and a blend of natural aggregates (>80%) and rubble from the other two mentioned groups. This indicates the difficulties associated with the grading of recycled aggregate [7]. Thomas et al. [8] have thoroughly characterize the RCA on the basis of their physical and mechanical properties and finally recommended that, 20% substitution of NCA with RCA can be made to prepare structural concrete. Further the utilization of recycled fine aggregate (RFA) as partial substitution of natural fine aggregate was investigated by researchers and the performance of concrete was observed to be degraded following the incorporation of RFA [9,10]. Apparently in the present study the scope of the study is limited to the usage of RCA and the aggregate extracted from laboratory crushed concrete specimens are exclusively the by-product of waste concrete. Hence, the liability to vary with the features of rubble does not exist. In this paper, recycled aggregates prepared from partially hydrated old concrete is studied. The concrete samples tested after 28 days of curing are used as the source of aggregates for new concrete.

The fresh concrete property (workability) is adversely affected by the addition of RCA because of its high water absorption. This is attributed to the porous mortar adhered to the RCA [7,11–15]. The researchers have reported 10% to 30% lower compressive strength of concrete made with RCA [7,11,16–18]. The previous studies reveal that the concrete made with RCA is also weak in tension and the reduction is more significant with the higher replacement ratio of RCA [11,19–23]. Apart from the replacement ratio, some other factors such as, the type of parent aggregate and its physical and mechanical properties, age and exposure condition of parent concrete, procedure of extraction of recycled aggregate and number of crushing stages involved [24,25], the amount of adhering mortar in RCA and aggregate surface texture also affect the mechanical properties of RAC [15,26]. In this regard researchers have employed different mix design approaches, such as Direct Weight Replacement (DWR) Method, Direct Volume Replacement (DVR) Method, Equivalent Mortar Replacement (EMR) Method [27] and Particle Packing Method (PPM) [28] to improve the quality of RAC. Further researchers have incorporated different mineral admixtures, such as Nano silica [29–31], silica fume, meta kaolin [32], flyash [10,32–35], ground granulated blast furnace slag [35,36] to improve the mechanical performance of RAC owing to the contribution of secondary hydration products. However, the addition of fibers to the recycled aggregate concrete mixture also helps in improving its mechanical behaviour [37]. The fibers used in concrete can be categorised as natural fibers and artificial fibers. The naturally available fibers which are mainly derived from the plant source like jute, hemp, coir, sisal, bamboo etc. In case of artificially prepared fibers the tensile properties are even higher than the naturally available fibers. The available artificial fibers are synthetic fibers or regenerated fibers namely glass fiber, carbon fiber, aramid fiber, steel fiber, polypropylene fiber etc. In this study polypropylene is used as fiber material because of its low density, non-corrosive and chemically inert properties, which makes them suitable to use as reinforcement in concrete.

The usage of polypropylene fiber (PP Fiber) improves of the tensile strength characteristics of concrete. Prasad and Kumar [38] incorporated PP fiber in RAC and reported an increment of 16% in split tensile strength and 6% in flexural tensile strength. Vytlačilová [37] confirmed the improved mechanical performance of RAC owing to the addition of PP fiber. In addition to the compressive strength and tensile strength, the bond strength is a vital mechanical parameter of reinforced concrete. Bond strength of concrete is essential during the transfer of axial force in between the steel and surrounding concrete and it is regulated by the union of these two materials. Ajdukiewicz and Kliszczewicz [21] reported a 20% drop in bond strength of RAC, which is made from 100% RCA. Xiao and Falkner [39] investigated the bond behaviour between RAC and steel bars (deformed and plain rebar) and noticed that the bond strength between RAC and the plain bars decreases with an increase in the RCA replacement percentage, which is due to the weak aggregate matrix interface bond in RAC. Choi and Kang [40] observed that, the bond strength has negligible effect up to 50% replacement percentage of RCA. Fathifazl et al. [41] reported that the bond performance of RAC is 18%–33% lower than the virgin aggregate concrete. Butler et al. [42] found that the bond strength of RCA concrete is 9%–19% lower than the conventional concrete under equivalent mix proportions. The previous studies on the mechanical performance of RAC indicates its inferiority to the conventional concrete. The limited literature on fiber reinforced recycled aggregate concrete signifies the interesting aspects of the usage of fiber in RAC. However, the literature available on the usage of PP fiber in RAC is very scant and as per the authors' knowledge, the mechanical performance of partially hydrated recycled aggregate concrete (PHRAC) with the incorporation of PP fiber has not been explored yet.

2. Research significance

The literature survey showed that at same w/c ratio concrete made with NCA is having better mechanical properties than RAC. In order to improve the mechanical properties of hardened RAC, various material processing methods, mix design methods, mixing approaches and curing procedures have been employed by the