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Behavior of polyester FRP tube encased recycled aggregate concrete with recycled clay brick aggregate: Size and slenderness ratio effects

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HIGHLIGHTS

- PFRP tube significantly increases the ductility of RAC-RCBA cylinders.
- Size and slenderness ratio affect the strength at the transitional point (f_{ct}).
- Wall effect existed in the small sized specimens.
- Size-dependent model was proposed and fit well with the experimental results.

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ABSTRACT

Compared with normal aggregate concrete, recycled aggregate concrete (RAC) containing recycled clay brick coarse aggregates (termed as RAC-RCBA) shows very lower compressive strength and larger variation in compressive strength, which hinder the application of RAC-RCBA as structural concrete. This study used polyester FRP (PFRP) as confining material of RAC-RCBA cylinders to improve the strength of RAC-RCBA. The axial compressive behavior of 42 PFRP tube encased RAC-RCBA cylinders (termed as PFRP confined RAC-RCBA) and 24 unconfined RAC-RCBA cylinders were investigated. Compared with conventional glass/carbon FRP (G/CFRP) materials, the main advantages to use PFRP are its much lower material cost and much larger tensile strain capacity. In this study, the experimental parameters considered were: (1) strength, (2) size, and (3) slenderness ratio of RAC-RCBA cylindrical specimens. Statistical analysis was also conducted to investigate the size effect and the slenderness ratio effect. The experimental results indicated that compared with conventional G/CFRP composites, the PFRP had a significantly lower tensile strength and modulus, but a much larger tensile strain at failure. The PFRP tube enhanced the ductility of the RAC-RCBA cylinders remarkably, while the enhancement on the compressive strength of RAC-RCBA by PFRP was not so pronounced as that by carbon/CFRP tubes. It was also found that the size and the slenderness ratio influenced the compressive strength of the RAC cylinders at the transitional point (f_{ct}) remarkably, and the f_{ct} decreased with the increase in size and slenderness ratio for middle, large and tall sized cylinders. In addition, a size-dependent model for f_{ct} was proposed and the predictions fitted well with the experimental results, the applicability of the proposed model for other weakly confined RAC-RCBA was also verified through the comparison with the experimental results of flax FRP tube confined RAC-RCBA.

1. Introduction

In each year, urbanization generates a huge amount of construction and demolition wastes (CDWs) in the world. Disposal of those wastes leads to an occupation and the waste of a large amount of farm lands and also causes environmental pollution issue [1]. Generally, the produce of construction materials will consume a large amount of natural resources that cannot be regenerated in a short time, thus it is a great waste if CDWs are only used for landfill. One of the most effective ways to solve CDWs disposal issue is to reuse them as recycled aggregates (RAs) of concrete, that is, to produce recycled aggregate concrete (RAC) where partial or all natural aggregates are replaced by RAs [2]. Due to a considerable amount of clay brick wastes generated in many countries in

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the last decades, the recycled clay brick aggregate (RCBA) probably became one of the most widely used RA types for RAC [3–5]. To date, extensive research has been carried out on RAC because of the superiority of RAC in environmental protection and cost saving [6–10]. Particularly, a large number of studies have focused on RAC containing RCBA (termed as RAC-RCBA) [11–13]. However, owing to the RCBAs with relatively low strength and high water absorption, the strength of the produced RAC-RCBA was not satisfactory as that of normal aggregate concrete (NAC) and the compressive properties of the RAC-RCBA also showed great variation [12,13]. Consequently, the application of RAC-RCBA was mainly restricted for non-structural construction such as landfill, rather than for structural concrete application [14,15].

Fiber reinforced polymer (FRP) composite, as one of the most effective confining materials for concrete, has been widely investigated to improve the strength and ductility of concrete due to the high strength, light-weight and corrosion resistance characters of FRP materials such as glass and carbon [16–27]. In literature, a popular form of FRP confined concrete is the concrete filled FRP tube (termed as CFFT). The effects of different experimental parameters on the compressive behavior of CFFT have been extensively studied [28–37], such as strength of unconfined concrete [28,29], confinement manner [30], slenderness ratio [32], type of fiber [33], overlap configuration [34], orientation of fiber [35], end conditions [35], and section shape [36]. Recently, there has been a trend to use FRP to RAC in order to improve the mechanical property of RAC, e.g. Islam et al. [38] and Xiao et al. [39] studied the compressive behavior of CFRP and GFRP confined RAC, respectively. Their studies indicated that the confinement provided by CFRP and GFRP enhanced the strength and ductility of RACs significantly. Xie and Ozbakkaloglu [40] stated that the axial compressive stress-strain curves of CFRP confined RAC were highly affected by the replacement ratio of RAs (i.e. 50% and 100% were used), the stress-strain curves of CFRP confined RAC did not exhibit the typical bilinear behavior like the FRP confined NAC. On the other hand, Chen et al. [41] concluded that the compressive stress-strain curves of CFRP-confined RAC with different replacement ratios of RAs (i.e. 0%, 25%, 50%, 75% and 100%) were similar to that of CFRP-confined NAC and these curves can be reasonably predicted by existing stress-strain models developed for FRP-confined NAC. These limited studies mentioned here showed that the findings from different authors on the compressive behavior of G/CFRP confined RAC are conflicting. Thus, the compressive behavior of FRP confined RAC should be better understood.

In practice, a wider application of CFRP and GFRP materials in civil engineering is limited by their high initial material prices. Against this background, nowadays researchers are trying to use new confining materials to replace conventional CFRP and GFRP for concrete to gain environmental and economic benefits. For example, Yan et al. [23–27] carried out a series of studies on plant-based natural flax FRP (FFRP) tube encased normal aggregate concrete and coir fiber reinforced concrete (CFRC). These researches indicated that the plant-based natural FFRP tube enhanced the bearing capacity and ductility of concrete remarkably, and also showed comparable confinement performance to those of concrete confined by GFRP and CFRP. Bai et al. [42] investigated polyethylene terephthalate (PET)-FRP and polyethylene naphthalene (PEN)-FRP confined normal concrete, the results indicated that the ductility of the confined concrete was improved remarkably due to the large rupture strain of the PET-FRP and PEN-FRP materials. Polyester is a synthetic polymer which has a large market share (i.e. 18%, ranges third place after polyethylene of 33.5% and polypropylene of 19.5%) of all plastic materials produced. The polyester has promising engineering application prospects due to its lower price (i.e. the polyester fabric is less than 1 US dollar per square meter, which is much lower than that of glass or carbon fabrics with the same size) and the larger rupture strain (i.e. can be up to 20%) compared with synthetic carbon and glass, and plant-based natural flax fiber [43,68,69]. Although the advantages of low cost and large rupture strain capacity of polyester FRP (PFRP), it should also be pointed out that the tensile strength of PFRP is normally significantly lower compared with those of glass or carbon FRP. Whether the low strength PFRP as confining material could provide comparable confinement performance to those of glass and carbon FRP on RAC, is unknown. This is a subject which needs to be clarified. In literature, research on the application of PFRP in civil engineering is rare. Huang et al. [44] studied on the compressive behavior of PFRP confined NAC and concluded that the ductility of the concrete increased significantly and the compressive strength of concrete was also improved to some extent. Another study investigated the feasibility of PFRP plates as external strengthening materials of RC beams [45]. This study concluded that the PFRP strengthening reinforcement enhanced the ductility, deflection and energy absorption of normal RC beams remarkably. Therefore, using PFRP as confining material of RAC-RCBA may facilitate the use of RAC-RCBA as structural concrete, since PFRP as confinement device has potential to enhance the strength of RACs to the level of NAC. Therefore, investigating on the feasibility of PFRP tube as confining material of RAC-RCBA has potential industrial significance.

Previous studies conducted by Bažant et al. [46–47] have confirmed the existence of size effect in NAC and other quasi-brittle materials. Neville et al. [48] also stated that the compressive strength of small sized NAC specimens can be affected due to the restriction by the loading plates of compression testing machine, especially for specimens with a low slenderness ratio, and the restriction caused the compressive results obtained from smaller and shorter specimens not representative for larger and taller sized NAC specimens. As for FRP confined NAC, conflicted conclusions have been drawn from different researchers on its size effect. De Lorenzis et al. [49], Carey et al. [50] and Gu et al. [51] pointed out that no obvious size effect was observed in FRP confined NAC, especially in NAC confined with relatively high level confinement and large specimen sizes. However, the results from Silva et al. [52], Masia et al. [53] and Tong et al. [54] demonstrated that the size effect clearly existed and the compressive strength of FRP confined NAC decreased as the specimen size increased. Wang and Wu [55] also investigated the size effect of aramid FRP confined NAC columns and concluded that size effect actually existed when the confinement ratio (i.e. f_l/f'_{co}, f_l refers to the confinement pressure provided by the FRP tube, f'_{co} indicates the compressive strength of the unconfined concrete) was relatively low, while size effect gradually disappeared as the confinement ratio increased, the critical value of confinement ratio was 0.67 according to the computation results. Most of previous studies [38–41] on FRP confined RACs were conducted on small sized (i.e. 300 mm in height and 150 mm in diameter) specimens. How the size may affect the compressive behavior of FRP confined RAC, is unknown. Against this background, this study also investigated the axial compressive behavior of PFRP-confined RAC-RCBA considering the effects of strength, size and slenderness ratio of RAC-RCBA cylinders. Furthermore, a size-dependent strength model was proposed based on Bažant's size-effect law [56] (Bažant's SEL) and Wang & Wu's model [55] to predict the compressive strength of PFRP confined RAC-RCBA at the transitional point of their axial compressive stress-strain curves.

2. Experimental section

2.1. Test matrix

In this study, axial compression test was carried out on 66 cylindrical specimens including 24 unconfined RAC-RCBA and 42 PFRP-