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Comparative evaluation of fire resistance of partition wall blocks prepared with waste materials

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Partition wall blocks produced by using recycled concrete as aggregates may be exposed to fire conditions in real applications. It is of great significance to keep the thermal conductivity of the block as low as possible to minimize damages due to the outbreak of a fire. To do so, alternative and/or additional materials can be used in the preparation of the blocks, which can reduce the heat transfer rate with little degradation of strength. In this study, three kinds of waste materials derived from construction and demolition (C&D) waste were respectively used to add or replace fine aggregates by volume or weight, including polypropylene fiber (PP fiber), recycled glass (RG) and recycled polystyrene (RP) in preparing the partition blocks. The compressive strength, water absorption, density, thermal conductivity, porosity of the blocks before and after exposure to elevated temperatures of 300 °C, 500°Cand 800 °C were examined. The results indicated that at room temperature, the incorporation of PP fibers had negligible influence on the physical properties of the blocks with little reduction of compressive strength, while the replacement of fine aggregate by RP resulted in significant reduction in compressive strength as well as thermal conductivity. The use of RG as a fine aggregate could reduce the thermal conductivity without significant effects on the compressive strength of the block samples. Although the exposure to elevated temperatures brought about reduction in thermal conductivity, the increase in porosity led to a large reduction in compressive strength of the blocks prepared with RP. The most significant finding of the study was that using 100% RG as fine aggregate was beneficial to conservation of compressive strength especially after exposure to 800 °C due to the re-solidification of the melted RG upon cooling, which led to a better thermal insulation property of the blocks. A further study on the influence of RG on compressive strength based on the mortar blocks prepared with glass cullet as fine aggregates convincingly proved the improved fire resistance of using 100% RG especially after 800 °C. The use of RG for partition blocks production has significant advantages in terms of sustainability and fire resistance.

1. Introduction

There have been increasing amounts of construction and demolition (C&D) wastes generated all over the world for the past few decades. For instance, in China, it was estimated that the production of C&D wastes was about 120 million tonnes in 2006 (Zhao et al., 2010). These waste materials, mainly consisted of concrete, glass, bricks, various types of polymers etc., can be potentially recycled. But nowadays they are mostly disposed of at landfills due to the general lack of knowledge on the feasibility for reusing them and legislation mandating their reuses. Furthermore, construction activities, as the largest consumer of natural materials, are exhausting natural resources (Gheni et al., 2017) and there is a pressing challenge to develop energy-efficient construction materials.

For the sustainable and economic development considerations, a lot of research studies have focused on developing methods for reuse and recycling these waste materials (Huang et al., 2002; Fatta et al., 2003; Evangelista and de Brito, 2007). Among them, for example, it has been experimentally verified that recycled concrete waste (RC) can be used as an alternative aggregate material to produce new concrete. However, the mechanical and durability properties of the new concrete with more than 30% replacement

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ratio of natural aggregates by RC are inferior to those prepared with only natural aggregates due to the higher porosity and water absorption characteristics of RC (Kou et al., 2012). These shortcomings have apparently restricted the utilization of RC in concrete. Whereas, some research studies reported that RC can also be used as aggregates for the production of concrete blocks using a dry-mixed method with the use of compression molding (Kou et al., 2012; Poon et al., 2002). Compared with wet-mixed conventional concrete, it has been demonstrated that using this dry-mixed approach to manufacture non-structural precast concrete blocks can better utilize the characteristics of recycled coarse and fine aggregates without concerning workability in the fresh state (Kou et al., 2012; Poon et al., 2002, 2009; Zhao et al., 2011), which is one of the alternatives toward the cleaner production of concrete products.

Precast concrete blocks prepared with RC by using the dry-mixed method with compressing molding are generally used for two applications: paving blocks and partition wall blocks. For partition wall blocks, they are non-structural building materials requiring only low to medium strength. Meanwhile, in order to achieve the target of energy efficiency, thermal characterization of the blocks is primarily needed to reduce heating and cooling energy use in buildings. Furthermore, buildings may be also exposed to fire conditions, representing significant fire hazard due to the large drop in load-bearing capacity and performance degradation when the components of the concrete with higher thermal conductivity rapidly decomposed and dehydrated under elevated temperatures. To counteract this potential problem, there is a need to produce concrete blocks with good fire resistance.

Almost no investigation on the performance of partition wall blocks using waste materials as aggregates under authentic fire conditions was reported because such experimental conditions are difficult to perform. However, several studies have been carried out on assessing the properties of partition wall blocks prepared with waste materials, such as recycled concrete, recycled glass and crushed brick, under elevated temperatures by simulated fire conditions. Zhao et al. (2011) prepared partition wall blocks using recycled concrete aggregate and clay brick, and examined the mechanical properties of the blocks after exposure to elevated temperatures of 300 °C, 500 °C and 800 °C. It was reported that all the concrete blocks at 300 °C had higher compressive strengths compared to those at room temperature. After 300 °C, both the compressive strength and flexural strength decreased with increasing temperatures. Furthermore, the flexural strength of the blocks having a higher recycled brick content was higher compared with others. Another investigation by Kou et al. (2012) displayed an improvement in both the compressive strength and transverse strength of the partition wall blocks prepared with fresh concrete wastes (FCW) at room temperature but reductions in mechanical properties after exposure to elevated temperatures. It is generally recognized that the fire damage of concrete is mainly due to the dehydration of C-S-H gel, the thermal incompatibility between cement paste and aggregate, as well as the buildup of vapor pressure in the cement matrix (Chan et al., 1999).

In order to enhance the fire resistance of concrete, several measures have been taken. For example, some experimental studies have shown that the inclusion of polypropylene (PP) fibers in concrete, especially in high performance concrete (HPC), can considerably reduce the risk of concrete spalling occurrence at elevated temperatures. Traditionally, the inclusion of fibers has been used as one of the ways to improve the tensile strength and reduce the drying shrinkage by creating a network of disordered distribution in the cementitious composites (Donkor and Obonyo, 2015; Mesbah et al., 2004). Recently, the investigation by Maluk et al. (2017) indicated that not only the dosage, but also the cross-section and individual length of PP fibers, have considerable effects on the effectiveness at reducing the propensity for heat-induced concrete spalling. Although three potential mechanisms, such as discontinuous reservoirs, continuous channels and/or vacated channels, may be the positive factors for the effectiveness of PP fibers to inhibit the spalling occurrence of concrete (Khoury, 2008), the mechanisms still need to be further explored.

Some other studies presented that foamed concrete has better fire resistance properties due to its lower thermal conductivity and diffusivity. Among them, Sayadi et al. (2016) and Vilches et al. (2012) investigated the effect of expanded polystyrene particles (EPS) on the fire resistance of foamed concrete and concluded that a higher fire endurance can be obtained for foamed concrete with a lower EPS volume of 28%. Based on the current theory, under high temperatures, the heat transfer through of porous materials, like concrete, is an inverse function of the number of air-solid interfaces traversed (Tan et al., 2017). But there is no report whether such a theory is suitable for the fire resistance of the partition wall blocks prepared with EPS.

Under elevated temperatures, blocks with a lower thermal conductivity can reduce the heat transfer rate inside the materials, leading to better load-bearing capacity and performance retention compared to conventional concrete blocks. Furthermore, slow heat transfer is advantageous for delaying the decomposition of the constituents in the blocks. This study focused on the evaluation of the fire resistance of the partition wall blocks principally prepared with RC, by comparing the mechanical property and thermal conductivity before and after exposure to elevated temperatures of 300 °C, 500°Cand 800 °C. Recycled concrete, obtained from a C&D waste recycling facility, was used as aggregates. For reducing heat transfer, the use of waste materials, including recycled glass, crushed foamed polystyrene and polypropylene fiber, as replacement or additional mixtures in the process of preparing the blocks was attempted. Fig. 1 illustrates a schematic overview of the whole experimental work, where recycled concrete, used as coarse aggregates, is coded as RC, polypropylene, as additional constituent of the concrete mixture, is coded as PP fiber, glass and polystyrene, as fine aggregate replacement in the mixture, are coded as RG and RP, respectively. Furthermore, 100%, 75%, 50% and 25% RG were used to replace river sand (RS) in additional mortar blocks prepared without the incorporation of coarse aggregates to further explore the influence of RG on compressive strength.

2. Experiment details

2.1. Materials

In this work, ASTM type I ordinary Portland cement was used. A crushed recycled concrete (RC) with a particle size of 5–10 mm was used as the coarse aggregate. RC, RG as well as RP with a maximum size of 5 mm were used as fine aggregates. PP fibers with a diameter of 45 μm and a length of 6 mm were used as an additional component in the mixture and it was obtained from WR Grace Ltd. in Hong Kong.

RC was sourced from a C&D waste recycling facility in Hong Kong. The facility processed crushed rock and concrete from civil engineering and building construction waste streams. RC (<5 mm) had a fineness modulus of 3.36. RG aggregates with a particle size of <3.55 mm and a fineness modulus of 4.02 were obtained from a local glass recycler. RP aggregates with a maximum size of 5 mm were obtained from crushing waste expanded polystyrene foams by using a laboratory abrasive tool. The RC and RG were first dried in the oven at 105 ± 5 °C for 24 h. The physical properties of the aggregates mentioned above were tested according to BS 882 (1992) and ASTM C128 and the results are tabulated in Table 1. The