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Performance of dry cast concrete blocks containing waste glass powder or polyethylene aggregates

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ABSTRACT

Dry-cast concrete blocks are a popular building material; however, to improve the economic and environmental sustainability of this industry, its dependence on natural aggregate and Portland cement needs to be reduced. To further this goal, blocks with up to 25% of the cement replaced with waste glass powder (WGP) or up to 15% of the sand replaced with high density polyethylene (HDPE) or low density polyethylene (LDPE) polymer pellets were produced in an industrial plant. The physical, mechanical and durability properties of the individual blocks and the mechanical properties of the block assemblages were tested. Based on statistical analyses, the blocks with 10% WGP as cement replacement performed similarly to the control blocks. The block properties were sensitive to the use of either type of polyethylene aggregate, which resulted in a decrease in strength and an increase in water absorption. Acceptable performance was achieved when 3–6% of the sand was substituted with polymer pellets.

1. Introduction

Masonry construction, which is a build-up of block units and mortar joints, has been a popular technique for millennia because it allows for quick, efficient, durable and economic construction. The continuation of this historic trend is possible provided that the masonry industry remains economically and environmentally sustainable. To meet this objective, the masonry industry needs to explore alternative methods that allow for the reduction of (a) non-renewable materials, (b) energy used in the production of the concrete block units, and (c) labour cost, while maintaining the same performance requirements. This study investigates the use of waste materials as alternatives to aggregate and cement in the production of concrete block units.

Waste materials as partial replacement of natural aggregates in concrete, including construction and demolition (C&D) waste [1], glass [2–5] and polymers [6–8], have been studied. A review of the literature has revealed that C&D waste and glass as partial aggregate replacement have been studied extensively in comparison to polymer waste. The results show on average a decrease in compressive strength and an increase in water absorption when C&D waste and glass are added as aggregate replacements. Furthermore, for glass, the development of alkali–silica reaction (ASR) gel remains a major concern [2–5,9]. With regard to polymers, a significant portion of recyclable polymers ends up in landfill due to the low cost of producing them from virgin material, mixing of polymer types during recycling, or contamination with other materials [10]. Ismail and Al-Hashmi [11] studied the effects of replacing fine aggregate, namely sand with polymer aggregate, concluding that a 20% sand replacement with waste polyethylene and polystyrene aggregate resulted in a 7% reduction in the density of the concrete [11]. Significant reduction in the compressive strength of concrete has also been observed [6–8]. Ghaly and Gill [6] reported a 29% decrease in compressive strength when 15% of the coarse aggregate was replaced by post-consumer waste polymer aggregate at a water to cement ratio (w/c) of 0.42; however, they also observed a more ductile failure mechanism. It should be noted that most of the research into the use of polymer aggregate has been on polyethylene terephthalate, commonly known as PET; the polymer used to manufacture plastic bottles [10]. Other polymers, such as low and high density polyethylene, which possess different properties, have not been thoroughly studied in this application.

Silica fume, fly ash and ground granulated blast furnace slag, which were once considered waste materials, are now used in the production of concrete and concrete blocks as supplementary cementitious material (SCM). Due to their pozzolanic properties, the partial cement replacement with these mineral admixtures

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has yielded improved physical, mechanical and durability properties, as well as improved the economic and environmental sustainability of the concrete industry [12]. Other researchers have studied the use of waste glass powder (WGP) as a SCM because of its high silica content [13–15]. Glass, which is an amorphous material, has been shown to exhibit pozzolanic properties when ground finer than 75 μm, [13,15,16]. Use of up to 30% WGP as cement replacement has yielded minor reduction in compressive strength when compared to the control at 28-days and comparable strength to the control at 90-days [13,14]. A recent study has shown that WGP at up to 10% cement replacement in concrete yields similar results to fly ash at the same replacement level after 90-days [17]. The main deterring factor for using WGP as cement replacement and/or glass particles as aggregate replacement remains ASR. However, data reported in the literature indicates that ASR due to WGP is nonexistent when the particle size is less than 45 μm [16].

The objective of the investigation is to study the effects of using post-consumer waste materials on the performance and production of dry-cast concrete masonry blocks [18]. WGP was used as cement replacement and, HDPE and LDPE polymer pellets were used as sand replacement. The blocks were produced in an industrial plant. The performance of the blocks was investigated through density, compressive strength, elastic modulus and bond strength analyses representing the physical and mechanical characteristics of the unit block and prism assemblage, and through water absorption, initial rate of absorption (IRA), and ASR analyses representing the durability of the concrete block.

2. Experimental investigation

2.1. Materials

Cement conforming to CSA type 30 HE [19], and WGP, which was obtained from a post-consumer waste source, were used as cementitious materials in the concrete mixtures. The chemical characteristics of the cement and WGP are given in Table 1. The maximum nominal particle size of WGP was 36 μm and the moisture content was less than 0.1%.

Crushed limestone with a maximum nominal size of 5 mm was used as the coarse aggregate. Siliceous sand, with a fineness modulus (FM) of 3.2 and particle size distribution given in Fig. 1 was used as fine aggregate. Low density polyethylene (LDPE) pellets, high density polyethylene (HDPE) pellets, and grafted HDPE pellets were also used as fine aggregate. The particle size distribution of the pellets is shown in Fig. 1. The FM for the LDPE, HDPE and grafted HDPE was 3.9, 4.1 and 3.6, respectively. These results indicate that the polymer aggregates have particles that are slightly coarser than those of the sand. The contact angle of the three polymers, given in Table 2, indicates that the polymers are hydrophobic. Two distinct contact angles were measured for the grafted HDPE indicating that the side chains are structurally distinct from the main chain.

Table 1
Chemical composition of cement and WGP.

Constituents (% by mass)	CSA type HE cement	WGP
SiO_2	20.89	70.59
Al_2O_3	6.09	2.03
Fe_2O_3	2.31	0.53
CaO	65.04	10.52
MgO	2.57	0.94
K_2O	0.88	0.52
Na_2O	0.22	13.37
TiO_2	0.29	0.06
MnO	0.05	0.02
P_2O_5	0.12	0.02
Cr_2O_3	0.00	0.06
LOI	1.53	1.25

2.2. Mixture proportions

The proportions of the control block mixture were based on the standard mixture used at the industrial plant. The cement content was partially replaced with WGP at 10% and 25% by weight. Sand was replaced, by volume, at 3%, 6%, 9% and 15% with LDPE and HDPE. The 15% replacement of the total sand was limited by the hydrophobic nature of polyethylene (PE) while the 3% grafted HDPE replacement of sand was limited by the supply. The concrete mixture proportions of the blocks are given in Table 3. The mass of coarse aggregate was 522 kg per batch for all 12 mixtures. The water to binder ratio (w/b) of the mixtures ranged between 0.23 and 0.34 with the corresponding average and coefficient of variance equal to 0.26 and 10%, respectively.

Structural type S mortar was used to build the prisms. The mortar mixture consisted of CSA type 10 GU cement [19], hydrated lime, sand and water. The mixture proportions are given in Table 4.

2.3. Production

2.3.1. Block

The blocks were produced in an industrial dry-cast block making plant. The mixing procedure was in accordance with the following steps: (1a) fine and coarse aggregates were added to the mixer and mixed for 20 s; (1b) for the blocks with polymer aggregate, the PE aggregate was added next and mixed for 20 s; (2a) cement was added and mixed for an additional 20 s; (2b) for the blocks containing WGP, WGP was added with the cement; (3) water was added to achieve the desired consistency. The total mixing time and amount of water added is given in Table 5.

The mixture was placed into steel moulds and consolidated. Because it is a dry-cast production, the uncured blocks were de-moulded immediately following consolidation and visually inspected. The geometry of the WGP blocks and the blocks containing 3% or 6% PE polymer aggregate was stable and no visual difference was observed between them and the control. Some of the blocks containing higher percentages of PE polymer aggregate were found to have cracks in the webs upon de-moulding. This is most likely caused by the repulsive forces generated between the hydrophobic polymer aggregates and water. For the blocks with 15% PE polymer aggregate, the change in their length and width was 1 mm–2 mm in comparison to the control blocks, the expansion was large enough to crack some of the blocks.

The blocks were steam cured for 12 h. One month after production, the blocks were shipped to the McMaster University Applied Dynamics Laboratory for testing.

2.3.2. Prism

Prisms were built by a certified mason to test the compressive strength and bond strength of the block assemblage. Accordingly, prisms four units high and one unit wide were constructed in a running bond pattern and stack pattern. The mortar joints were 10 mm thick with face shell bedding and a concave profile.

2.4. Test program

2.4.1. Physical and mechanical characteristics

The density of the blocks was determined in accordance with ASTM C140 [21]. The reported values represent the average of the results of five blocks. The compressive strength of the blocks was tested following the procedure outlined by ASTM C140 [21]. Five blocks were tested per mixture and were capped according