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Using waste materials and by-products to produce concrete paving blocks

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HIGHLIGHTS

- Compressed paving blocks could be successfully prepared using cement and waste materials.
- Ground granulated blast furnace slag (GGBS) was more effective in reducing cement content than ROSA, BOS, PG and BPD.
- The concrete paving blocks prepared with OPC7/GGBS6.3/BPD0.7 can reduce cement content by up to 30%.

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ABSTRACT

Using by-product and waste materials, such as ground granulated blast furnace (GGBS), cement by-pass dust (BPD), run-of-station ash (ROSA), basic oxygen slag (BOS), plasterboard gypsum (PG), incinerator bottom ash aggregate (IBAA), recycle crushed glass (RCG), recycled concrete aggregate (RCA), recycled bricks (RB), steel fibre (SF) and PVA-Fibre for the production of environmentally friendly paving blocks is explored. The combinations of binary and ternary cementitious blends in different mixes are considered. Paving blocks were tested for split tensile strength at 14 and 28 days, slip/skid resistance (BPN), weathering resistance and density were also measured on some selected mixes. The tests results confirmed that a concrete paving mix containing 6.3% GGBS, 0.7%, BPD and 7.0% OPC by weight can decrease Portland cement content by 30% in comparison to the percentage currently being used in most factories, without having a substantial impact on the strength or durability of the paving blocks produced in accordance with BS EN 1338:2003.

1. Introduction

When Portland cement is produced, it has a significant negative impact on the environment; this is due to the production of carbon dioxide emissions in production of Portland cement. Therefore, if it is possible to decrease the quantity of Portland cement and replace the content with other non carbon dioxide producing cementitious materials, the carbon footprint of concrete products will be significantly reduced without adversely affecting its durability and other physical characteristics.

Portland cement is an essential material used in almost all relevant civil engineering applications. Ghataora et al. [1] reported that the production of every tonne of Portland cement releases approximately 1 tonne of carbon dioxide. Carbon dioxide is a key contributor to the greenhouse gas emissions that are causing global warming. Cement production accounts for roughly 8% of global CO_2 emissions [2].

Since 1970, attempts have been made to partially replace Portland cements with other materials in concrete [3]. It was discovered that some types of pozzolans, limestones and metakaolin, which occur naturally, are possible alternatives to Portland cement [4]. Other materials, such as fly ash and steel slag which are produced by various metallurgy processes are also possible alternatives [4–6].

The literature shows that no cement replacement is used in paving blocks manufacturing except for GGBS and PFA which are used in some of the paving block factories in UK. However, no researcher has been found to try to reduce the cement content of paving blocks using other by products or waste cementitious/pozzolanic materials. Other researchers have been using different recycled construction materials as a replacement for aggregate in paving blocks [7–9] but no cement replacement is researched.

Fischer and Werge [10] claim that about 850 million tonnes of construction and demolition waste is generated in the EU per year.

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This represents 31% of the total waste generated in the EU. Furthermore, the survey by McGrath group [11] confirmed that nearly 40 million tonnes of recycled aggregates are produced in the UK each year which account for only about 20% of the total aggregates market [11].

The aim of this research is to investigate possible alternative materials in the manufacture of paving blocks using a mixture of waste materials in order to reduce the percentage of Portland cement. As less Portland cement is used, the CO_2 levels of the products will also be reduced. Therefore, not only will this process decrease the stockpile of waste materials but will also decrease the impact of concrete products on the environment as well as problems associated with disposing waste materials to landfill sites.

2. Materials used in this research

2.1. Ground granulated blast-furnace slag (GGBS)

Ground granulated blast-furnace slag 'GGBS' is a cement substitute, it is a by-product produced during the production of iron. The chemical composition of oxides in GGBS is similar to that of Portland cement but the proportion of oxides in GGBS is different from Portland cement as presented in Table 2 [12].

The ground granulated blast-furnace slag (GGBS) was obtained from Civil and Marine, which is part of Hanson UK. The grain sizes were in the range of 0.3 μm and 0.1 mm, with an average particle size of 20 μm. The particle size distribution is given in Table 1. The material was marketed under the BS EN 15167-1-2 standard [13]. The specific gravity of the GGBS used was about 3.4.

2.2. Cement by-pass dust (BPD)

By-pass dust (BPD) is a by-product collected from the kiln bypass. As a result, BPD contains numerous cement bound phases. For this research, BPD from local cement company, Castle Cement (Heidelberg cement group in Rugby, UK) was obtained for this research. The BPD was provided in powder form, the average size of fine particles was found to be 10 μm, and the maximum particle size was noted to be 200 microns. The particle size distribution is given in Table 1. The specific gravity of the BPD used was about 2.6.

2.3. Plasterboard gypsum (PG)

For this research crushed plasterboard gypsum waste was supplied by Lafarge plasterboard recycling plant in Bristol. Plasterboard gypsum is obtained from a number of sources; construction and demolition sites are the most common sources, once the plasterboard gypsum is obtained the plasterboard is recycled (by grinding and sieving) and all contaminants such as paper and glass are eliminated. The average particle size was found to be >300 μm, the range was between 1 μm and 1 mm. The particle size distribution is given in Table 1. The specific gravity of the PG was about 2.3.

2.4. Basic oxygen slag (BOS)

Basic oxygen slag otherwise known as steel slag dust is a by-product generated during the conversion of iron into steel. During the current production of steel it is inevitable that basic oxygen steel slag will be produced. For this research, the basic oxygen slag was obtained from the Corus plant at Scunthorpe, and the average particle size was 40–60 μm. The particle size distribution is given in Table 1. The specific gravity of the BOS used was about 3.2.

Table 1
The particle size distribution of the materials used.

Aperture (μm)	Percentage of passing (%)				
	GGBS	ROSA	BPD	BOS	PG
100	97.95	82.76	97.17	76.83	13.32
75	94.45	79.26	94.97	72.23	12.22
50	89.35	75.56	92.07	68.43	11.42
30	85.15	71.96	85.37	66.03	11.02
10	82.35	69.56	80.67	64.23	10.72
5	81.65	69.06	80.27	63.83	10.62
1	97.95	82.76	97.17	76.83	13.32

Table 2
Chemical content of raw materials used.

Sample	OPC (%)	BOS (%)	ROSA (%)	PG (%)	PBD (%)	GGBS (%)
SiO_2	20.00	11.43	45.91	2.43	21.86	37.28
TiO_2	–	0.39	1.41	0.03	0.29	0.58
Al_2O_3	6.00	1.60	26.51	0.81	3.85	10.79
Fe_2O_3	3.00	28.24	5.23	0.36	2.57	0.43
MnO	–	4.35	0.08	<0.01	0.02	0.68
MgO	1.50	8.27	2.13	0.40	1.13	8.83
CaO	63.00	41.29	6.88	37.30	53.40	40.12
Na_2O	1.00	0.02	0.61	0.03	0.41	0.27
K_2O	1.00	0.02	1.35	0.24	3.64	0.37
P_2O_5	–	1.48	0.98	0.02	0.08	<0.05
SO_3	2.00	0.44	1.37	53.07	7.10	0.15
LoI	0.50	3.12	7.11	4.09	5.64	1.03

2.5. Run-off-station ash (ROSA)

Run-off-station ash is an unclassified type of fly ash; it is gathered from chimney stacks of power stations. Run-off-station ash is pozzolanic. Cementitious compounds, such as calcium silicate and aluminate hydrates, are formed when run-off-station ash reacts with calcium hydroxide and alkalis. For this research dry run-off-station ash has been obtained from Rugby Ash with an average particle size of 20 μm. The particle size distribution is given in Table 1. The specific gravity of the ROSA was about 1.6.

2.6. Ordinary Portland cement (OPC)

The cement used for this research was CEM1 cement, as defined by the European standard BSEN-197 [14]. The specific gravity of the cement used was about 3.1.

2.7. Incinerator bottom ash aggregate (IBAA)

In this material the term 'ash' is slightly misleading because the material is not pure powder; it also contains traces of glass, brick, rubble, sand, grit, metal, stone, concrete, ceramics and fused clinker as well as combusted products, such as ash and slag. Incinerator bottom ash aggregate (IBAA) is an environmentally friendly material with a consistency, which makes it easy to handle and use. In this research incinerator bottom ash aggregate (IBAA) was obtained from Day Group LTD and the sizes used were 4 mm and 6 mm with the same grading (after blending of the different size fractions) as shown in Fig. 1.

2.8. Recycled crushed glass (RCG)

When used in construction applications, waste glass must be crushed and screened to produce an appropriate design gradation [15]. Crushed glass or cullet, if properly sized and processed, can exhibit characteristics similar to that of gravel or sand.

For this research recycled glass was obtained from Day Group Ltd. 4 mm natural aggregates were replaced with recycled crushed glass of the same grading (after blending of the different size fractions) as shown Fig. 1.

2.9. Recycled concrete aggregate (RCA)

Recycled concrete aggregates are aggregates derived from the processing of materials previously used in construction. For this research recycled concrete aggregate (RCA) was obtained from the civil engineering laboratory at Coventry University. Two types of RCA were used: RCA I, this consisted of normal concrete cubes which were made in laboratory under standard curing and RCA II, which consisted of normal concrete slabs, were from demolished structures.

For the production of paving blocks the used concrete cubes and slabs were firstly crushed manually using a hammer, and then sieved to a required grade, finally, they were ready for use as a 100% replacement for 6 mm natural aggregates with the same grading (after blending of the different size fractions) as shown Fig. 1.

2.10. Recycled bricks (RB)

Clay brick is mainly produced in construction and demolition sites where it is most commonly delivered to landfills or reclamation sites for disposal. As landfill space and reclamation areas are becoming more and more limited, it is important to explore the possible use of crushed clay brick as a civil engineering material. This study investigated the use of crushed brick to fully replace 6 mm natural aggregates in paving blocks. The brick for this study was delivered to the laboratory from a demolition site in Coventry University campus. Similar to the RCA, the bricks were