Development of novel cementitious binders using plasterboard waste and pozzolanic materials for road bases

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ABSTRACT: This paper explores the potential benefits of utilising combination blends of plasterboard waste gypsum and pozzolanic materials in developing novel cementations pastes with lower environmental impact in comparison with conventional Portland cement. Ternary blend systems based on waste plasterboard from construction demolishing sites (PG), basic oxygen slag from steel factories (BOS) and cement kiln dust (CKD)/by past dust (BPD) from cement industries were investigated. PG, up to 30%, BOS and CKD, up to 90% were incorporated as total binder replacements for preparation of various combinations of binary and ternary blended systems to achieve the highest compressive strength. A water-binder ratio of 0.3 was used for the main group of paste mixes. Cube compressive strength was determined at the age of 3, 7 and 28 days. Based on the obtained results, the effect of PG and CKD on activation of slag with respect to compressive strength was investigated. It was found that the relation between slag content and compressive strength is sensitive to the amount and chemical composition of PG and CKD/BPD used in ternary system. In ternary system of PG-BPD-BOS, incorporation of 10% PG together with 36% BPD resulted in the highest compressive strength while in CKD-PG-BOS system; the highest compressive strength is achieved using 20% CKD and 16% PG. A road foundation site trial was successfully conducted in summer 2006 using this developed binder for road base in a car park area at Lowdham Grange prison, Mansfield construction site.

1 INTRODUCTION

The environmental challenge in terms of reducing global carbon dioxide emissions, conservation of energy, reducing reliance on prime resources and reuse of by-product and waste materials are driving the search for new cementitious materials and the development of more environmentally friendly binders to be used in construction works. The reuse of construction and demolition wastes together with various sources of pozzolanic waste materials is an attractive alternative to produce cementitious binders with a lower strength than ordinary Portland cement. These low strength binders can be used in many applications such as structural fills, insulation and isolation fills, pavement bases and sub-bases, conduit bedding, erosion control, void filling, nuclear facilities and bridge reclamation [ACI 1999].

Plasterboard gypsum (PG) offcut waste arising from construction and demolition sites is one of the challenging waste materials produced in the UK after it was reclassified by EU Landfill Directive as hazardous non-inert wastes in July 2005. The majority of plasterboard gypsum waste used to be traditionally landfilled and co-disposed of with other wastes. [WRAP 2005]. Detailed statistics on waste plasterboard arisings are currently scarce, but it is estimated that some 300,000 tonnes of waste plasterboard are generated each year from new construction activity (largely as offcuts). The amount of plasterboard waste arising from demolition projects is more difficult to quantify, but maybe in the range 500,000 tonnes to more than 1 million tonne per annual in the UK [WRAP 2006].

This investigation is aimed at developing novel-low environmental impact cementitious binder utilising blends of plasterboard gypsum waste and a range of pozzolanic industrial waste materials such as basic oxygen slag, cement kiln dust and cement by pass dust. The above materials were used in binary and ternary systems with the aim of exploiting the potential synergy between these materials to form a cementitious matrix. A site trial was also conducted using selected proportions of blended materials to make a roller compacted concrete as a sub-base for a car park.

2 EXPERIMENTAL PROGRAMME

2.1 *Materials*

Crushed plasterboard gypsum (PG) used throughout the investigations was obtained from the Lafarge plasterboard recycling plant located in Bristol. The plasterboard was dried, ground and passed through 600 µm sieve in order to increase the reactivity of the particles and also to remove paper pieces mixed with gypsum. The basic oxygen slag (BOS) was obtained from Tarmac UK (Corus Scuntrorpe plant). The slag has been ground using laboratory ball mill and sieved through a 600 micron sieve. The cement kiln dust CKD and cement by pass dust (BPD) were supplied by Castle Cement (Heidelberg cement group) both in the form of powder. The main difference between CKD and BPD is related to the temperature at which these materials are produced. CKD is taken out of the kiln during where the temperature is about 300 °C; however, BPD is from the kiln where the temperature is about 1000 °C. The chemical compositions of raw materials used in this investigation are presented in Table 1.

Table 1. Chemical compositions of starting materials

Oxides	PG %	BOS %	BPD %	CKD %
SiO_2	2.43	11.43	12.86	9.89
TiO_2	0.03	0.39	0.12	0.14
Al_2O_3	0.81	1.60	3.50	3.72
Fe_2O_3	0.36	28.24	2.12	1.24
MnO	0.00	4.35	0.02	0.02
MgO	0.40	8.27	2.46	0.94
CaO	37.30	41.29	58.28	40.42
Na_2O	0.03	0.02	0.29	0.43
K_2O	0.24	0.02	1.71	6.36
P_2O_5	0.02	1.48	0.06	0.08
SO_3	53.07	0.44	6.75	5.59
LOI	4.09	1.12	10.23	30.99

2.2 *Mix proportions*

The proportioning of pastes used in this investigation is designed in order to achieve the highest compressive strength of binary and ternary mixtures. For ternary system of PG, BPD and BOS in the first stage the optimum proportion of BPD and BOS was determined by measuring the compressive strength of various binary mixtures of BPD and BOS. In the second stage, PG was added to the optimum mixture of BPD-BOS corresponding to the highest compressive strength obtained in the first stage. Table 2 shows the mix proportion of paste mixes used. The similar experimental plan was adopted for the ternary mixture of CKD, PG and BOS.

Table 2. Mix proportions for PG-BPD-BOS paste mixture

Mix Code	PG %	CKD %	BOS %	L/S	Flow %
PG10/BOS90	10	-	90	0	172
PG20/BOS80	20	-	80	0.3	150
PG40/BOS60	40	-	60	0.3	136
PG60/BOS40	60	-	40	0.3	110
CKD60/PG 8/BOS32	8	60	32	0.3	161
CKD40/PG12/BOS48	12	40	48	0.3	120
CKD20/PG16/BOS64	16	20	64	0.3	92
CKD10/PG18/BOS72	18	10	72	0.3	76

The mix proportions of paste incorporating CKD, PG and BOS is shown Table 3. The constant liquid to solid ratio of 0.3 was use in all mixes. The flow of all the mixes investigated were measured using the flow table according to ASTM C109.

Table 3. Mix proportions for CKD-PG-BOS paste mixture

Mix Code	PG %	BPD %	BOS %	L/S	Flow %
BPD10/BOS90	-	10	90	0.3	87
BPD20/BOS80	-	20	80	0.3	33.5
BPD40/BOS60	-	40	60	0.3	38.5
BPD60/BOS40	-	60	40	0.3	16.8
BPD90/BOS10	-	90	10	0.3	12.8
PG5/BPD38/BOS57	5	38	57	0.3	128.8
PG10/BPD36/BOS54	10	36	54	0.3	125.6
PG15/BPD34/BOS51	15	34	51	0.3	103
PG20/BPD32/BOS48	20	32	48	0.3	101.7
PG30/BPD28/BOS42	30	28	42	0.3	47.6

2.3 *Casting and curing*

Paste specimens 50 mm cubes were cast for the determination of compressive strength. All the specimens were cast and fully compacted in three layers using a vibrating table. After casting, the samples were covered by polyethylene sheets for 24 hour. The samples were demolded the following day and then kept at 20±1 ºC and 98±1% RH prior to testing at 3, 7 and 28 days.

3 RESULTS AND DISCUSSION

Compressive strength development of binary and ternary mixtures containing PG, BPD and BOS are shown in Figures 1 and 2. The strength development of paste mixes using a range of BPD and BOS showed that in the binary system the mix containing 40% of by pass dust and 60% of slag has the highest strength at 7 days, although it can be seen in Figure 1 that the optimum amount of BPD for 3 days strength is equal to 60%, which could be because of rapid reacting components of by pass dust used. At 28 days the highest compressive strength was still achieved by the mix of BPD40/BOS60.

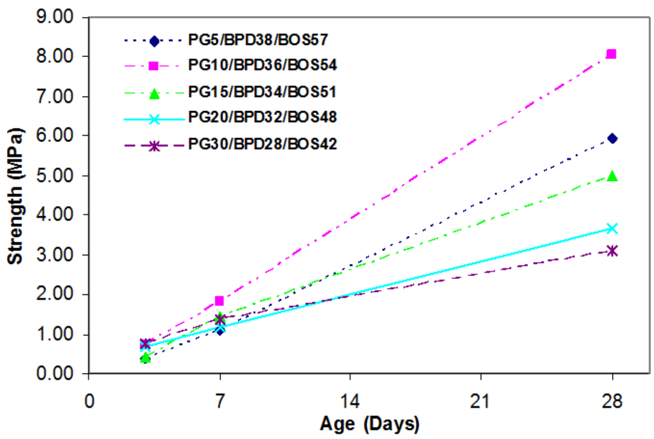

Figure 1. Compressive strength development of pastes containing BPD and BOS

In the ternary system, Figures 2 shows that the highest strength at 3, 7 and 28 days corresponds to the mix containing 10% of plasterboard gypsum. It can be seen that increasing the amount of PG above 10% resulted in decrease in compressive strength. Therefore, it can be concluded that the

mixture PG10/BPD36/BOS54 is the optimum mixture in this
optimization order.

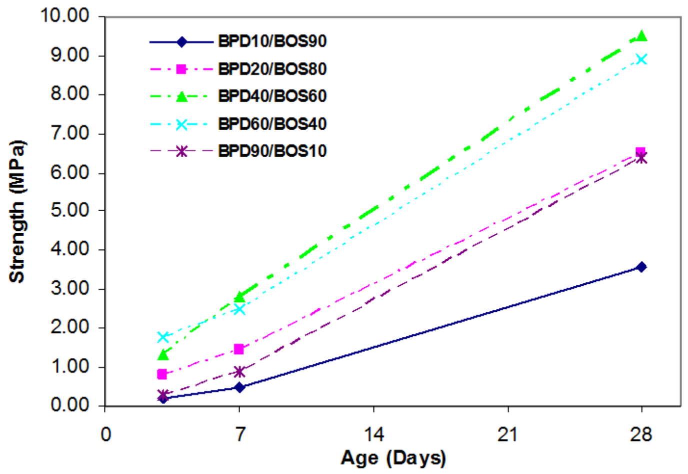

Figure 2. Compressive strength development of pastes containing PG, BPD and BOS

Figures 3 and 4 show the compressive strength development of binary and ternary mixtures of PG-BOS and PG-CKD-BOS respectively. It can be seen that in the binary system mix incorporating 20% PG and 80% BOS achieved the highest compressive strength compared to mixes with higher content of slag.

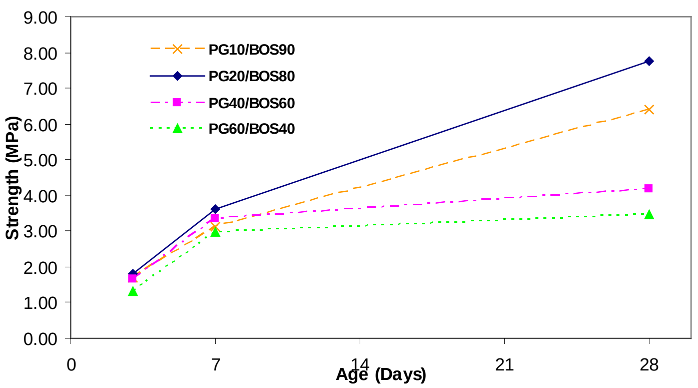

Figure 3. Compressive strength development of pastes containing PG and BOS

In the ternary system, the highest compressive strength was obtained from the mix with 20% CKD, 16%PG and 64% BOS. It can also be observed that as a result of increasing the amount of CKD from 40 to 60% compressive strength has been reduced by about 50% at 28 days.

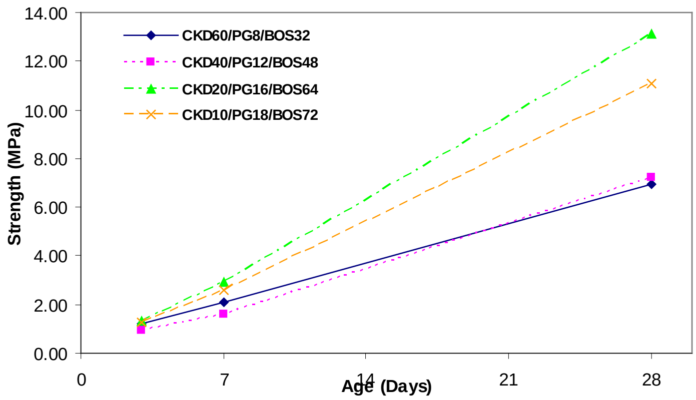

Figure 4. Compressive strength development of pastes containing CKD, PG and BOS

In general slag is typically hydrated after mixing with Portland cement or other alkali materials such as CKD and BPD providing a source of alkalinity with which the slag reacts to form cement hydration products [Neville 2000]. The excessive amount of alkali in the system has a detrimental effect on hydration of alkali activated slag causing a delay of setting and low strength. The precise causes of this behaviour have not been clarified. The formation of monosulphate due to instability of ettringite at high pH has been suggested to be the main reason [Ottemann et al 1951].

Comparison of mixtures containing CKD and BPD revealed that the highest strength achieved from optimization experiments was related to chemical composition of alkali source and alkali content in the mixture. It was observed that two sources of alkali in this investigation resulted in different ternary proportions corresponding to the highest compressive strength. The ternary mix PG16/CKD20/BOS64 showed higher strength than mix PG10/BPD36/BOS54. It implies that activating effect of CKD on BOS was more remarkable than BPD in the ternary systems. This might be attributed to amount of alkalis released from these two sources of waste alkali materials.

With respect to the effect of gypsum on compressive strength, as stated by Matschei et al [2005] the early compressive strength of supersuphated cements was enhanced by sulphate activation of the slag in comparison with slag mixes without any addition of calcium sulphate. This phenomenon can be observed in results obtained from PG, BPD and BOS mixtures shown in Figures 1 and 2.

4 SITE TRIAL

As part of the site trials conducted in this project, a 6 by 17 m car park area at Lowdham Granage prison construction site at Nothingham was constrcted with Roller Compacted Concrete (RCC) as a sub-base layer using the novel developed binder. Based on numerous laboratory mixes, the final optimised proportions of the ternary mixture of PG, BPD and BOS obtained in this project were chosen for the site trials. Considering the volume of materials need for site trilas, over 100 T of blended powder was prepared. The novel binder consisted of BOS, ground PG and supplied as blended powder. Figure 5 shows the bagged and shrink wrapped blended powder delivered to the ready mix plant for roller compacted concrete mix.

Figure 5. Blended powder delivered to ready mix plant in 20-kg bags

The roller compacted concrete designed through laboratory experiments was deemed appoint for this. The concrete mix design used is presented in Table 4. The area was stripped of the existing hardcore to expose the sub grade, which was hard clay. The roller compacted concrete mix was prepared at a Lafarge ready mix concrete plant at Lockington, Leicestershire.

Mix Code	Mix Proportions (kg/m3)			W/B	Slump mm
	Blended novel binder	Water	Recycled Agg.		
RA-RCC	400	100	1900	0.3	0

Table 4. Mix proportions of concrete mix used in Lowdham Grange site trial

A layer of 160 mm of concrete was placed over the sub-grade layer using the truck mixer chute and spread and levelled manually. As the concrete was delivered in three truck loads; placing and compaction of RCC layer was carried out in three segments of the allocated area. Figures 6 and 7 show the placing and levelling of the roller compacted concrete.

Figure 6. Placing concrete using truck mixer chute

Figure 7. Spreading the concrete using a mechanical excavator

The placed concrete layer was then compacted using a 3-Tonne vibrating roller in accordance with the compaction requirements of the Specification for Highways Works to form a 100 mm roller compacted concrete layer as shown in Figures 8. The surface of the concrete was sprayed with a bituminous emulsion layer to prevent evaporation of water up to 28 days curing. The strength development of RCC placed in site trial and performance of the sub-base concrete layer was evaluated constantly by means of cores and visual observation. The site trial evaluation results will be available for presentation at the conference.

Figure 8. Concrete compaction using a 3-tonne vibrating roller

5 CONCLUSIONS

Crushed plasterboard gypsum can be used as a source of sulphate together with basic oxygen slag and cement kiln dust/by pass dust to form a sulphate activated pozzolan.

The optimum usage amount of plasterboard waste gypsum depends on the chemical properties of basic oxygen slag and cement kiln dust/by pass dust. Laboratory experiments showed that in ternary combination of PG-CKD-BOS using 16% crushed plasterboard gypsum resulted in the highest compressive strength.

Increasing by pass dust content in ternary combinations of PG, BOS and CKD/BPD resulted in less compressive strength. This can be due the location and orientation of ettringite formed around slag particles.

Roller compacted concrete (RCC) made with optimum proportions of BOS, PG and BPD with W/B ratio of 0.25 was successfully used as the sub-base layer in the car park site trail.

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