Plasterboard and Gypsum Waste in a Novel Cementitious Binder for Road Construction

Essie Ganjian, Homayoon Sadeghi Pouya and Peter Claisse (Coventry University); Malcolm Waddell (WRAP); Steve Hemmings (Lafarge Plasterboard); Sofie Johansson (Skanska)

Coventry University in collaboration with Skanska and Lafarge Plasterboard recently undertook research for WRAP (Waste & Resources Action Programme) to develop a cost effective novel binder using recycled gypsum from waste plasterboard and a range of mineral wastes for construction of road foundations. This research was part of WRAP's plasterboard programme to divert plasterboard waste from landfill by developing markets for recycled gypsum. The project included laboratory testing and a series of onsite trials at Lowdham Grange Prison and King's Mill Hospital construction sites in Nottinghamshire. These successfully proved that recycled gypsum can be used in a number of road construction applications. This has demonstrated an innovative method of reuse for gypsum waste as a cementitious binder for use in the production of cementitious products.

Plasterboard gypsum waste recycling

Plasterboard is made of a gypsum plaster core with a paper facing. It is a widely used construction material for applications such as forming partitions, lining walls and ceilings. Around 3 million tonnes of plasterboard are manufactured and used in the UK each year, and this is increasing by approximately 10% per year.

From its use, plasterboard waste arises during installation through wasteful design, off-cuts, damaged boards, and over-ordering. Wastage of 10%-35% often occurs on sites, with a recent WRAP study into plasterboard usage on Skanska projects found that wastage on site were typically 18-26%. This leads to around 300,000 tonnes of plasterboard waste being produced each year from this source. Waste also arises from its removal, such as from removing partitions, refurbishing wall and ceiling linings, repairing damaged linings, and from complete soft-strip before demolition of a building. It is estimated that in total more than one million tonnes of plasterboard waste is produced in the UK each year.

Although plasterboard waste from all these sources can be recycled, the vast majority is still disposed to landfill. It is increasingly necessary to find alternatives to this, due to factors such as:

- Increases in landfill tax increasing the cost of disposal to landfill year on year;
- Decreasing available space in landfill sites;
- The requirement in the landfill regulations that gypsum-based materials disposed of to landfill must be deposited in a specially engineered ‘high-sulphate’ monocells in a non-hazardous landfill site, leading to increased disposal costs [1].

Supersulphated cement

Blast furnace slag is a by product of steel manufacture and formed when molten blast-furnace slag is rapidly cooled [2]. Blast furnace slag cement in concrete is typically hydrated after mixing with Portland cement providing a source of alkalinity with which the slag reacts to form cement hydration products. Cement made from granulated blast furnace slag activated by means of calcium sulphate and alkalis is known in the UK as supersulphated cement [3].

Alternative sources of gypsum such as plasterboard waste and red gypsum (Titano-gypsum) can be used with slag and other sources of alkalis such as slaked lime or cement kiln dust to produce sulfate-alkali activated slag cement. In this project crushed plasterboard gypsum waste has been used successfully as an activator in slag-cement kiln dust mixture to develop a cost effective novel binder. Basic Oxygen Slag (BOS) was used in place of the more common Blast Furnace Slag because it is a waste.

Laboratory research

A series of laboratory trials were undertaken to determine the optimum proportions of recycled gypsum and mineral wastes required to achieve the highest compressive strength. Initial trials were carried out on waste mixes for binder paste (i.e. a mixture of cementitious powder and water with no aggregate). Waste plasterboard was ground, and then sieved to remove the facing paper. The gypsum powder was mixed with a range of industrial by products such as ground basic oxygen slag (BOS), Cement Kiln Dust and By Pass Dust (CKD/BPD), run of station ash (ROSA), slaked lime and other potential binder materials to form a paste. Different paste, mortar and concrete mixes, were then produced using conventional and by-product aggregates in an attempt to identify lowcost, medium strength formulations for road construction applications. A series of soil stabilisation experiments using novel techniques were also carried out to determine the optimum binder content for soil sub-grade stabilisation applications.

The "novel binder" mix

The research identified that a mix of 15% plasterboard-derived recycled gypsum (PG), 5% bypass dust (BPD) and 80% basic oxygen slag (BOS) was the optimum combination of these materials. This gave a compressive strength of around 11MPa at a water to binder ratio of 0.3. This combination is referred to as the "novel binder" mix.

To check the environmental impact of the novel binder the laboratory research also included an investigation of whether any hydrogen sulphide would be emitted due to the degradation of the paper content in the recycled gypsum. It was found that incorporating up to 50% extra paper in paste mixtures had no adverse effect on the emission of hydrogen sulphide from paste or concrete made with the novel binder. Tests also demonstrated that no heavy metals or other hazardous elements leached from paste made with the novel binder when tested using a high pressure through-flow test.

The site trials

The optimum combination of 15% PG, 5% BPD and 80% BOS was tested in three site trials to demonstrate the use and performance of the novel binder in the following applications:

- Soil stabilisation;
- Semi-dry roller compacted paste (grout); and
- Roller compacted concrete (RCC).

Two sites were used to conduct the trials in July 2006, and evaluated until Feb 2007. An area in the King's Mill hospital construction site in Nottinghamshire was allocated to make a 22 metre access road using the novel binder to stabilise soil for the sub-base and semi-dry paste (grout) as the base course. A car park at the Lowdham Grange prison construction site at Nottingham was used for a trial of RCC as a sub-base.

Site trial 1: soil stabilisation

According to results obtained from the soil stabilisation experiments undertaken at the laboratory, the novel binder could be used to stabilise soil containing clay and/or sand. A mix of 50% binder had, 1.5 MPa compressive strength at 7 days when measured according to standard recommendations in TRL 248.

To construct a 300mm layer of stabilised soil using 50% novel binder, first 150 mm of soil was spread on the existing sub grade and levelled using an excavator. The binder was then applied on top of the soil and spread using the excavator to achieve a uniform 150 mm layer. The mixture of soil and binder was blended using a rotavating blending machine as shown in figure 1. In order to achieve the optimum moisture required for reaction and optimum compaction of the soil-binder mixture, water was added using a mobile sprinkler and the mixture was then blended again using the rotavator and levelled using the excavator.

Figure 1. Blending the mixture of soil and binder using the rotavator

The stabilised soil was compacted using a 10-tonne vibrating roller. Figure 2 shows the levelled stabilised soil and final compacted layer.

Figure 2. Compacting of the blended soil and the binder using the 10-tonne roller

Site trial 2: semi-dry roller compacted paste (grout)

As with ordinary Portland cement concrete, water content in paste and concrete mixes plays a significant role in compressive strength development of the novel binder. The lower the water content, the higher the compressive strength. Semi-dry roller compacted paste using the novel binder with 13% water achieved the highest compressive strength of 31MPa at 28 days and was therefore used for the base course in the road site trial. This material was laid in the form of a layer of 100mm semi-dry roller compacted paste on top of soil that had been previously stabilised using the novel binder.

A self-contained lorry mounted volumetric mixer was used. The semi-dry paste was spread and levelled using an excavator and by hand as shown in figure 3. The paste layer was then compacted using a 3-tonne vibrating roller, as shown in figure 4.

Figure 3. Spreading and levelling the semi-dry paste

Figure 4. Compacting of the semi-dry paste layer using a 3-tonne roller

Site trial 3: roller compacted concrete (RCC)

Owing to the slow-reacting nature of the novel binder, RCC seemed to be a perfect way to produce concrete with compressive strength of 10-12MPa at 28 days. An RCC mix with water to binder ratio of 0.25 and design strength of 11MPa was used as the sub-base in the Lowdham Grange prison car park trial.

The RCC mix was prepared at a Lafarge ready mix concrete plant. Once delivered to site, it was placed over the sub-grade layer, and manually spread and levelled to a thickness of 160mm (figure 5). It was 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 figure 6.

Figure 5. Placing and spreading the concrete

Figure 6. Concrete compaction using a 3-tonne vibrating roller

Evaluation of the Site Trials

Evaluation of the site trials carried out at 28, 90, 180 and 360 days indicated satisfactory performance of semi-dry roller compacted paste and RCC (see Fig 7). Core samples were obtained from different locations of the trial road and car park. They confirmed that the compressive strength of the sub-bases made with the novel binder was similar or higher than the designed lab strength at 28 days, with continuous growth of up to 50% and 62% at 180 and 360 days. It was confirmed that mixes incorporating slag and gypsum develop strength at a slower rate than ordinary Portland cement mixes and therefore sufficient time must be allowed for setting and curing [4].

Other applications for the novel binder

The positive results of these trials suggest that there may be wider applications for the novel binder beyond road construction, possibly:

- Construction products, such as paving slabs, kerbs and blocks;
- Trench reinstatement following utility works;

- Backfilling applications, such as cut and cover tunnels and stabilising mines; and
- Stabilising embankments.

Concluding remarks

Crushed plasterboard gypsum waste can be used as a source of sulphate to form a novel sulphate activated pozzolan binder with slag and by pass dust. Laboratory experiments showed that a mix of 15% gypsum, 5% cement bypass dust and 80% basic oxygen slag was the optimum combination of these materials. This novel cementitious blend can be treated like cement for road construction and other applications. The novel binder was used successfully in site trials to stabilise sub-grade, construct sub-base of a road using semi-dry grout and construct sub-base of a car park using roller compacted concrete. The results of this project revealed the potential of waste plasterboard gypsum and other industrials wastes such as basic oxygen slag and cement by-pass dust to make a cost effective binder with a great range of applications.

References

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