Plasterboard case study

Recycled gypsum in a novel cementitious material

This case study describes the development of cost effective novel cementitious mixes using recycled gypsum from waste plasterboard and a range of mineral wastes. Trials were undertaken of its use for the construction of road foundations.
WRAP

WRAP (Waste & Resources Action Programme) works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.

Established as a not-for-profit company in 2000, WRAP is backed by Government funding from Defra and the devolved administrations in Scotland, Wales and Northern Ireland.

WRAP and plasterboard

Through its Construction Programme, WRAP is helping the construction industry cut costs and increase efficiency through the better use of materials.

WRAP receives funding from Defra through the Business Resource Efficiency and Waste (BREW) programme to divert plasterboard waste from landfill by working to overcome the barriers to plasterboard recycling. Additional funding is also received from the devolved administrations in Scotland, Wales and Northern Ireland.

WRAP is developing a number of initiatives which are supporting the segregation, collection and recycling of waste plasterboard, and the development of end-market uses for the resulting recycled gypsum.

More information on WRAP’s work can be found on www.wrap.org.uk
Summary

Cements are substances which set and harden and can be used to bind other materials together. They are used throughout the construction industry, in a wide variety of applications, such as concrete. Gypsum is a key component in cementitious products and comes from natural sources, and a range of synthetic sources as a by-product of industrial processes. Alternatively, recycled gypsum from waste plasterboard also has the potential to be used in cements.

Coventry University, Lafarge Plasterboard Ltd and Skanska UK Ltd have recently worked together on a WRAP funded project to develop cost effective novel cementitious mixes using recycled gypsum from waste plasterboard and a range of mineral wastes for the construction of road foundations. The project included laboratory testing followed by a series of trials on construction sites at Loldham Grange Prison and King’s Mill Hospital, Nottinghamshire. These successfully proved that recycled gypsum can be used in a number of road construction applications including:

- soil stabilisation;
- semi-dry roller compacted paste; and
- roller compacted concrete.

This has demonstrated an innovative method of reuse for the construction industry that will minimise the volume of plasterboard waste sent to landfill, thus reducing disposal costs, whilst expanding the current markets for waste plasterboard.

This case study demonstrates that recycled gypsum can be used in a number of road foundation applications and that it is possible to close the loop by recycling waste plasterboard back into construction materials.
Background

Plasterboard 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. Over 2.5 million tonnes of plasterboard are manufactured and used in the UK each year, and this is increasing.

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, leading to around 300,000 tonnes of plasterboard waste being produced each year from this source. It 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;
- available space in landfill sites decreasing;
- the Landfill Regulations now requiring that quantities of gypsum-based materials being disposed of to landfill must be deposited in a specially engineered “high-sulfate monocell” in a non-hazardous landfill site, leading to increased disposal costs.

One alternative is to recycle any waste that is produced, and this case study looks at its use in the production of cementitious products, that set and harden and can be used to bind other materials together.
Supersulfated cement
Blast furnace slag is a by-product of steel manufacture and is formed when molten blast-furnace slag is rapidly cooled. Blast furnace slag’s major use is in the production of slag cement, primarily high slag blast furnace cement and Portland blast furnace cement.

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 sulfate and alkalis is known in the UK as “supersulfated cement”. The cement is made by grinding a mixture of 80-85% granulated slag, 10-15% anhydrite (hard-burned gypsum), and about 5% Portland cement.

Alternative sources of gypsum such as waste plasterboard and red gypsum (a contaminated waste from the manufacture of titanium dioxide) 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.

The companies in this case study are working together to reduce the amount of plasterboard waste being sent to landfill by developing cost effective novel cementitious mixes using recycled gypsum and a range of mineral wastes for construction of road foundations.
Project overview

Coventry University, Lafarge Plasterboard Ltd and Skanska UK Plc worked together on this WRAP funded project. It commenced in October 2005 and involved laboratory based research and site trials over a 16-month period.

The initial laboratory based research determined the optimum proportions of recycled gypsum and mineral wastes required for a binder paste to achieve the highest compressive strength. Site trials were then carried out to test the optimum mix of binder paste ingredients.

Skanska UK Plc provided two sites on which a total of three trials were carried out. A car park at the Lowdham Grange prison construction site in Nottingham was selected for testing Roller Compacted Concrete (RCC) as a sub-base layer using the novel developed binder. The second site was at the King’s Mill hospital construction site in Nottinghamshire. This site was used to trial the construction of a 22 metre access road using the novel binder to stabilise soil for the sub-base, and a semi-dry paste (grout) made from the novel binder for the base course.
Organisation overviews

Three organisations were involved in this research project. Coventry University led the research with support from two industrial collaborating partners, Lafarge Plasterboard Ltd and Skanska UK plc.

Coventry University

The laboratory research was carried out by a team of specialists at the Department of the Built Environment within the Faculty of Engineering and Computing at Coventry University. The team are active in their research into cementitious materials and was the lead partner in this project.

Lafarge Plasterboard Ltd

Lafarge Plasterboard Ltd is a manufacturer of plasterboard and jointing products. They were founded in 1987, in Bristol, and are now one of the three plasterboard manufacturers in the UK.

Lafarge Plasterboard Ltd is committed to designing recyclable products and systems, and reducing waste to a minimum. Life Cycle Assessments play a key role in their analysis, with the objective to make products which contribute to the protection of the environment. For example, the lining papers of plasterboard sheets are made using 100% recycled paper, and they use secondary resources wherever possible. They also strive to reduce the process energy used at their plants, and aim to produce products that will help improve the quality of life in buildings and conserve energy.

Lafarge Plasterboard Ltd supplied the waste plasterboard from which the gypsum was recycled for use in this project.
Skanska UK Plc

Skanska UK Plc is the second largest construction services contractor in the UK and is a leading PFI/PPP service provider. They combine design, building, civil engineering and building services with a wide range of specialist skills, to offer integrated project solutions, with total lifecycle considerations. Skanska UK Plc is committed to waste reduction and recycling. They provided the active construction sites for site trials and undertook the construction of the pavement layers using the novel materials developed.
Previous work

Over the past five years Coventry University, with the support of ENTRUST and a consortium of Mineral Industry Research Organisation (MIRO) members has carried out a successful research project developing novel composite landfill liners, made from industrial by-products; effectively “using waste to contain waste”. One major outcome of this work has been a range of low-cost, low permeability cementitious materials for use as waste containment structures and barriers.

Coventry University and Imperial College have also recently completed work on a contract for Huntsman Tioxide to develop uses for red gypsum. The work included an 8m³ trial pour of a controlled low strength material using red gypsum and oxygen slag dust as a trench backfill.

Having been inspired by results obtained from these previous projects, Coventry University investigated a new approach to the use of recycled gypsum from waste plasterboard, combined with other industrial wastes in developing a novel cementitious binder.
The approach

Laboratory research

A series of laboratory trials were undertaken to determine the optimum proportions of recycled gypsum and mineral wastes required for a binder paste (i.e. a mixture of cementitious powder and water with no aggregate) to achieve the highest compressive strength.

Methodology

Producing the recycled gypsum powder

The gypsum used in the research was recycled from waste plasterboard obtained from the Lafarge Plasterboard recycling plant in Bristol. The waste was in the form of construction off-cuts, and included some contamination such as fragments of paper and glass.

In the laboratory the waste plasterboard was ground, then sieved to remove the facing paper from the plasterboard and the contaminants. The resulting recycled gypsum was a fine reactive powder with less than 1% paper fibre content.

Blending the binder paste

The gypsum powder was mixed with a range of industrial by-products such as ground basic oxygen slag (BOS), cement kiln dust/by pass dust (CKD/BPD), run of station ash (ROSA), slaked lime and other potential binder materials to form a paste.
Different pastes, mortar and concrete mixes, were produced using conventional and by-product aggregates in an attempt to identify low-cost, medium strength formulations for specific road construction applications. The laboratory work investigated:

- the optimum proportion of these ingredients to achieve the highest compressive strength;
- the chemical interaction of the different materials; and
- their permeability and leaching characteristics.

A series of soil stabilisation experiments using novel techniques were also carried out to provide further information on the optimum binder content for the mixes and determine the performance of the materials.
Results of the laboratory testing

The laboratory research demonstrated that recycled gypsum could be used as a source of sulfate together with slag and cement kiln dust/by pass dust to form a sulfate activated pozzolan (a material which when combined with calcium hydroxide exhibits cementitious properties). It also demonstrated that an optimum proportion of gypsum depended on the chemical properties of slag and CKD/BPD.

The “novel binder” mix

The research identified that a mix of 15% plasterboard-derived recycled gypsum (PG), 5% CKD/BPD and 80% 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 throughout this case study. ROSA also showed satisfactory pozzolanic potential when used with slag and recycled gypsum. Using 30% ROSA and 15% PG, with 5% BPD and 50% BOS resulted in relatively higher compressive strength (21MPa) than other proportions, although this mix was not investigated further in the site trials.

Assessment of environmental impact

If gypsum is combined with biodegradable material under certain conditions hydrogen sulfide can be produced. The laboratory research included investigation of whether any hydrogen sulfide would be emitted due to the degradation of the paper content in the recycled gypsum with the gypsum itself.

It was found that incorporating up to 50% extra paper in paste mixtures had no adverse effect on the emission of hydrogen
sulfide from paste or concrete made with the novel binder and no trace of hydrogen sulfide was found from any of the developed mixtures.

Tests also demonstrated that no heavy metals or other hazardous elements leached from the paste made with novel binder when tested using high pressure through flow test. The concentration of sulfate and calcium leached was higher than from ordinary Portland cement paste, but this was not considered to be an environmental concern.

**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, with evaluation of constructed layers carried out until Feb 2007. An area in the King’s Mill hospital construction site in Nottinghamshire was allocated to make a 22 metre long access road using the novel binder to stabilise soil for the sub-base, and grout made from the novel binder 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 layer using the novel binder.

**Site trial 1: soil stabilisation**

According to results obtained from the soil stabilisation experiments undertaken at the laboratory, the novel binder could be used as a cementitious component to stabilise soil containing
clay and/or sand. Using a mix of 50% binder resulted in acceptable compressive strength according to standard recommendations set out in Transport Research Laboratory (TRL) report 248.

The binder was used in the same way as Portland cement, mixed with the soil at various ratios and optimum moisture contents to give a satisfactory compressive strength of 1-1.5MPa at 7 days after being compacted.

**Methodology**

The King's Mill Hospital soil stabilisation experiment was undertaken as follows:

1. The access road site was prepared by stripping the existing aggregate layers to expose the sub grade, which was sandy. The area was then trimmed to level, compacted and inspected.
2. To construct a 300mm layer of stabilised soil using 50% novel binder, first a 150mm of soil was spread and levelled using an excavator.
3. The novel binder was then applied on top of the soil, spread using the excavator and by hand to achieve a uniform 150mm layer.
4. The mixture of soil and binder was blended using a rotavating blending machine as shown in the photograph below. The powerful and heavy blade of the machine provided a homogeneous blend along the road.
5. As the moisture content of the soil used was not high enough to provide the optimum reaction and compaction of the soil-binder mixture, extra water was added using a mobile sprinkler, as shown in the photograph below. The mixture was then blended again using rotavator and levelled using the excavator.
6. The stabilised soil was compacted using a 10-tonne vibrating roller. The photograph below shows the levelled stabilised soil and final compacted layer.

7. In order to protect the stabilised soil from rain and evaporation a bituminous emulsion layer was sprayed on top of the finished surface.

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

As with ordinary Portland cement concrete, water content in paste and concrete mixes was found to play a significant role in compressive strength development. The lower the water content, the higher the compressive strength. Grout using the novel binder with 13% water achieved the highest compressive strength of around 31MPa at 28 days age. Roller compacted grout was therefore used for the base course in the road site trial. This material was laid on top of the soil that had been previously stabilised using the novel binder at the King’s Mill Hospital access road.
Methodology

The King’s Mill Hospital roller compacted grout experiment was undertaken as follows:

1. A layer of 100mm grout was designed to be laid on top of the stabilised soil. This layer was laid for half of the length of the access road in order to compare with the conventional base course which was laid on the other half.
2. As the water content of the semi-dry paste was limited to 13%, a volumetric mixer was used to mix the binder with water. The mixer contained a vessel to accommodate the binder and a 1600 litre tank of water. The binder passed to a screw by means of a belt conveyor where the water was added and mixed in the extending arm. The grout was spread through the extended arm of the volumetric mixer and then levelled using the excavator and by hand. The photograph below shows the mixing and spreading of the grout.
3. The grout layer was then compacted using a 3-tonne vibrating roller, as shown in the photograph below.

4. The surface of the roller compacted grout was sprayed with bituminous emulsion to aid its curing. At a later stage the other half of the trial road base course was laid using a standard aggregate design. The whole length of the road was then paved with 50 mm of bituminous surfacing.

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 acceptable compressive strength of 10-12MPa at age of 28 days. During the laboratory study RCC made with the novel binder showed higher compressive strength compared to mixes which included standard super plasticiser. An RCC mix with a water to binder ratio of 0.25 and designed strength of 11MPa was used as the sub-base layer in the Lowdham Grange prison car park trial.
Methodology

The Lowdham Grange prison RCC experiment was undertaken as follows:

1. The site was prepared by stripping the existing aggregate layers to expose the sub grade, which was hard clay. This was trimmed to level, compacted and inspected.

2. The RCC mix was prepared at a Lafarge ready mix concrete plant at Lockington, Leicestershire. Once delivered to site, it was placed over the sub-grade layer using the truck mixer chute, and manually spread and levelled to a thickness of 160mm.

3. As the concrete was delivered in three truck loads, placing and compaction of the RCC layer was carried out in three segments of the allocated area. A slightly different moisture content and compaction level was therefore expected for the sections. However, the workability of the mixes on site was observed to be very consistent.
4. The concrete layer 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 the photograph below.

Results of the Site Trials

Evaluation of the site trials carried out at 28, 90 and 180 days indicated satisfactory performance of semi-dry roller compacted paste and RCC.

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 to the designed lab strength at 28 days, with continuous growth of up to 50% at 180 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.

The site trials also confirmed that the novel binder could be used to stabilise soil containing clay and/or sand. Using 50% binder resulted in acceptable compressive strength according to TRL standard recommendations. Furthermore, increasing the binder content, increases the compressive strength.
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 utilities works;
- backfilling applications, such as cut and cover tunnels and stabilising mine shafts; and
- stabilising embankments.

Further work into these applications would reveal the huge potential for using recycled gypsum with other readily available pozzolanic wastes to make suitable binders as viable replacements for cement.
Conclusions

This case study has demonstrated that plasterboard waste can be successfully used in low-medium strength concrete mixes for the foundations of minor roads and car parks. The laboratory based research and site trials have shown that:

- The optimum combination for the novel binder was a mix of 15% recycled gypsum from waste plasterboard, 5% bypass dust, and 80% basic oxygen slag, which gave a compressive strength of 11MPa at a water to binder ratio of 0.3.

- The novel binder could be used as a cementitious component to stabilise soil containing clay and/or sand.

- Semi-dry roller compacted paste (grout) using the novel binder with 13% water achieved the highest compressive strength of around 31MPa at 28 days age.

- The novel binder developed strength at a slower rate than ordinary Portland cement, so sufficient time must be allowed for the setting and curing.

- Due to the slow strength development of the binder, roller compacted concrete (RCC) seemed to be the perfect way to lay the road base layer with acceptable compressive strength of 10-12 MPa at age of 28 days.

- The same equipment used for mixing regular concrete was used for the novel binder site trials. There was no specialist equipment required for the research.

The research team at Coventry University have proved through successful laboratory testing and site trials that plasterboard waste can be a useful material in the construction industry. The novel binder is a blend entirely from by-product wastes and recycled materials and can be applied to numerous applications where cementitious properties are required.
This has demonstrated an innovative method of reuse for the construction industry that will minimise the volume of plasterboard waste sent to landfill, thus reducing disposal costs, whilst expanding the current markets for plasterboard waste.
Contact details

**Coventry University**

Dr Essie Ganjian, Prof Peter Claisse and Homayoon Sadeghi Pouya  
Department of the Built Environment  
Coventry University  
Priory Street  
Coventry  
CV1 5FB

Tel: 024 7688 7625

Email: E.Ganjian@coventry.ac.uk

**Lafarge Plasterboard Limited**

Marsh Lane  
Easton-in-Gordano  
Bristol  
BS20 0NF

Tel: 01275 377 773

Fax: 01275 377 737
Skanska UK

Maple Cross House
Denham Way
Maple Cross
Rickmansworth
Hertfordshire
WD3 9SW

Tel: 01923 776 666

Email: skanska@skanska.co.uk
This case study was developed for WRAP by Enviros and CIRIA

We do not give any warranty, condition, guarantee or representation, expressed or implied, relating to information contained within this report.

The information contained herein is of a general nature only and is not intended to be relied upon in specific cases. We do not endorse the companies, recycling schemes or methodologies referred to within this report and it is recommended that you seek expert professional advice on specific issues.

The information does not take account of environmental or health and safety issues which you should discuss as a matter of routine with the appropriate regulatory authorities.

Under no circumstances will WRAP or their sub-contractors be liable for any loss, expense or damage caused by your reliance on the information contained within this report or any information obtained through our website.