Use of recycled plasterboard in unfired clay-gypsum blocks

Final report on operational trials to develop the use of recycled plasterboard in unfired clay-gypsum blocks for a range of construction applications

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Front cover photograph: Unfired clay-gypsum blocks containing 50% recycled plasterboard

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Context

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.

Plasterboard is used extensively in the construction and refurbishment of buildings as a lining for walls and ceilings, and for forming structures such as partitions.

Plasterboard waste can arise on construction sites for a number of reasons, including wasteful design, off-cuts from its installation, damaged boards, and over-ordering. It is estimated that over 300,000 tonnes per year of waste plasterboard is produced on construction sites. It can also arise from strip-out activities during refurbishment and demolition projects; the waste arisings from this source are significantly higher. In total it is estimated that over one million tonnes of waste plasterboard are produced each year from construction and demolition activities.

Most of this waste is currently disposed to landfill, even though it can be easily recycled. 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 working to overcome these barriers through the following key areas:
- plasterboard waste minimisation;
- site waste management;
- segregation and collection of plasterboard waste;
- development of infrastructure, including waste logistics and recycling capacity;
- market development for materials from plasterboard recycling – recycled gypsum and reclaimed paper;
- education, awareness and behavioural change; and
- informing and influencing legislation, regulations and policy.

More information on WRAP’s work can be found at www.wrap.org.uk/construction
**Executive summary**

Over one million tonnes of waste plasterboard are estimated to be produced each year in the UK from construction and demolition activities. Most of this waste is currently sent to landfill, even though it can easily be recycled. WRAP is working to divert plasterboard waste from landfill by seeking to overcome the barriers to plasterboard recycling. One area of its work is to develop markets for the materials from plasterboard recycling (recycled gypsum and reclaimed paper). This project evaluated the use of waste plasterboard as the source of the gypsum in novel unfired gypsum-clay construction blocks.

The collaborative project was led by Akristos Limited and also involved two brick companies (Baggeridge Brick and Hanson Red Bank), two plasterboard recyclers (Roy Hatfield Limited and Atritor Limited) and a number of consultants including the BRE Centre in Innovative Construction at the University of Bath and Natural Building Technologies.

**Trial design and results**

A series of laboratory-scale and production-scale trials were carried out during the project at the Measham works belonging to Hanson Red Bank. Production constraints during the project timescale unfortunately limited the work that could be undertaken at Baggeridge Brick's Sedgley works.

Target performance characteristics for the gypsum-clay block product were developed from two benchmark products – a clay-fibre block (Karphosit) and a gypsum block (Promonta) – imported into the UK. Die designs for extrusion trials at Hanson Red Bank featuring a block design of 440 × 220 × 120 mm were also developed.

Some processing was required before waste plasterboard could be used as a feedstock in the manufacture of the gypsum-clay blocks. The process at Roy Hatfield incorporates a series of shredding, crushing and air-separation processes to produce a 10–15 mm material. This was the material used in the laboratory- and production-scale trials. The Atritor process based on a turbo separator also produced comparable material (<15 mm), but the plant did not have the capacity to produce sufficient material for production-scale trials.

Preliminary development work using Keuper Marl/Grog clay blend (from the Measham works of Hanson Red Bank) and Etruria Marl clay blend (from the Sedgley works of Baggeridge Brick) suggested that 50% addition of recycled plasterboard (by volume) would be most appropriate.

All larger scale trials used a blend of processed plasterboard supplied by Roy Hatfield Ltd on a 50 : 50 volume basis with Keuper Marl clay. Use of a front-end loader and a bucket blending technique was shown to more suitable than use of a bulk bag discharge unit for the preparation of the amount of plasterboard-clay mix required for the production-scale trials. Before being used in the trials, the blend was dry ground in a hammer mill to give a free-flowing mix containing particles <2 mm in size.

The project team examined the compressed earth block machine available from Dutch company Oskam V/F in order to evaluate the potential of pressing (the traditional method for manufacturing concrete blocks) for production of the novel blocks. However, it was felt that pressing a fine plasterboard-clay mix could be problematical and extrusion was felt to a more suitable technology.

Initial trials using the horizontal extruder and a standard die at Hanson Red Bank's Measham works were successful in producing a block product containing 100% clay. Successful production of a small number of blocks with the 50 : 50 recycled plasterboard-clay blend on the more labour-intensive vertical extruder at Measham gave confidence to proceed to a production-scale trial using the more efficient horizontal extruder together with its purpose-built die. The gypsum-clay blocks made on the horizontal extruder were used for performance testing (compressive strength, flexural strength, abrasion resistance, etc.) and to build a number of demonstration walls.

A traditional cement : sand mortar proved ineffective but a mortar system based on clay, silica sand and sodium silicate produced excellent results. A thin joint mortar system was applied successfully using a cartridge gun or trowel.

A professional brick layer using the blocks to build one of the demonstration walls highlighted issues with the slight curvature of the blocks and their weight. The former arises during manufacture when lifting the heavy blocks. Both problems can be avoided by producing a lighter 100 mm block. No significant problems were
encountered during the use of common construction site tools and the application of common methods of chasing and fixing, though the profiled nature of the blocks caused some difficulties for the bricklayer at corners and the large horizontal holes raised issues regarding mortar application. The latter problem could be reduced with a 100 mm block with smaller perforation holes.

A professional plasterer applied five different plasters with and without primer to the same demonstration wall. Gypsum plasters were not satisfactory and the use of a lime, lime cement or clay plaster was considered the best choice.

**Conclusions**

Unfired gypsum-clay blocks have been successfully manufactured using recycled plasterboard in a horizontal extrusion process. Production trials used a blend containing 50% recycled plasterboard as the gypsum source. Horizontal extrusion proved more efficient than vertical extrusion.

The gypsum-clay product has enhanced physical properties compared with natural clay.

A number of mortar systems were investigated and a sodium silicate based mortar was found to give an excellent bond with the unfired gypsum-clay blocks. A number of plaster systems were also assessed and a number of material options are available which complement the blocks.

Unlike traditional fired clay construction units, the block products are not fired but are air or force dried. Their production therefore gives rise to fewer carbon dioxide emissions and the blocks have a low embodied energy. The blocks contain little or no cement (unlike cement-bonded aggregate blocks) and do not require recalcination of the gypsum to facilitate its recycling before it is incorporated into the block.

The gypsum-clay product has the potential to incorporate plasterboard from new build sources as well as from construction and demolition (C&D) sites where contamination levels are potentially higher. Minimal pre-processing of the recycled plasterboard is required as the fibre content of the backing paper has the potential to improve the flexural strength and ‘fixing’ properties of the block.

Unfired gypsum-clay blocks containing 50% recycled plasterboard and having a thickness of 100 mm are now available on a commercial basis.

An initial assessment of the market for such products indicates that there is an immediate market for over one million blocks per year. Assuming a 50% addition, this would create an annual market for over 9,000 tonnes of recycled plasterboard.

**Recommendations**

Further work is recommended to:

- optimise the content of recycled plasterboard in the block product;
- address the water resistance/water proofing of the unfired block (thus broadening the market for the product into applications where it can compete against traditional concrete blocks); and
- improve the compressive strength of the product (thus allowing it to be used in more demanding structural environments).
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1.0 Introduction
Growing interest in the use of unfired clay materials in construction in recent years has resulted in products such as clay blocks, bricks, mortars and plasters now being available. The use of recycled materials such as plasterboard within unfired clay products provides an opportunity for waste from the construction industry to be fully utilised as part of another product for use back in the industry.

This project investigated the use of recycled plasterboard within a novel unfired clay construction block which has the potential to be utilised in a number of construction product applications. Natural unfired clay was used as a binding agent and to facilitate extrusion or pressing of the composite blocks using traditional brick making technology. The gypsum–clay blocks were air-dried or force-dried (using waste heat) to develop a block product with a low embodied energy and containing a significant proportion of recycled plasterboard.

1.1 Trial design
The project was led by Andrew Biggs of Akristos Limited – a company that seeks to create novel markets for industrial waste products by utilising them as alternative raw materials via the brick, aggregate, cement and other industries. The other project partners are listed in Table 1.

Table 1 Project partners

<table>
<thead>
<tr>
<th>Role</th>
<th>Organisation</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead contractor</td>
<td>Akristos Limited</td>
<td><a href="http://www.akristos.com">www.akristos.com</a></td>
</tr>
<tr>
<td>Brick companies</td>
<td>Baggeridge Brick plc</td>
<td><a href="http://www.baggeridge.co.uk">www.baggeridge.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>Red Bank Manufacturing Company - a trading division of Hanson Building Products UK</td>
<td><a href="http://www.redbankmfg.co.uk">www.redbankmfg.co.uk</a></td>
</tr>
<tr>
<td>Plasterboard recyclers</td>
<td>Roy Hatfield Limited</td>
<td><a href="http://www.royhatfield.com">www.royhatfield.com</a></td>
</tr>
<tr>
<td></td>
<td>Atritor Limited</td>
<td><a href="http://www.atritor.com">www.atritor.com</a></td>
</tr>
<tr>
<td>Consultants</td>
<td>BRE Centre in Innovative Construction Materials, University of Bath</td>
<td><a href="http://www.bath.ac.uk/bre/">www.bath.ac.uk/bre/</a></td>
</tr>
<tr>
<td></td>
<td>Natural Building Technologies</td>
<td><a href="http://www.natural-building.co.uk">www.natural-building.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>Neil Sullivan and Associates Limited</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mike Walker</td>
<td></td>
</tr>
</tbody>
</table>

The project addressed the technical, processing, environmental, commercial and logistical supply chain challenges arising from the use of recycled plasterboard in the gypsum–clay block.

After preliminary laboratory investigations involving appropriate mix design development and product testing, full-scale factory trials were undertaken to demonstrate and establish the technical, economic and environmental benefits of using recycled plasterboard in the manufacture of a natural block product.

1.2 Materials used in the project

1.2.1 Clays
Two clays were examined as part of the project:
- Keuper Marl/Grog clay blend from Hanson Red Banks’s site at Measham in Derbyshire; and
- Etruria Marl clay blend from Baggeridge’s site at Sedgley near Dudley in the West Midlands.

Both clays are used by the brick industry to produce a range of extruded and soft mud fired brick products, and are readily available from a number of brick companies and mineral operators.

Table 2 shows the chemical analysis of the two clays.
Table 2 Chemical analysis of the Keuper and Etruria Marl clays

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Keuper Marl (Hanson Red Bank Measham works)</th>
<th>Etruria Marl (Baggeridge Sedgley works)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O (sodium oxide)</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>MgO (magnesium oxide)</td>
<td>0.78</td>
<td>2.13</td>
</tr>
<tr>
<td>Al$_2$O$_3$ (aluminium oxide)</td>
<td>20.11</td>
<td>23.50</td>
</tr>
<tr>
<td>SiO$_2$ (silicon dioxide)</td>
<td>56.55</td>
<td>60.98</td>
</tr>
<tr>
<td>P$_2$O$_5$ (phosphorous pentoxide)</td>
<td>nd</td>
<td>0.24</td>
</tr>
<tr>
<td>K$_2$O (potassium oxide)</td>
<td>1.89</td>
<td>2.21</td>
</tr>
<tr>
<td>CaO (calcium oxide)</td>
<td>0.42</td>
<td>0.46</td>
</tr>
<tr>
<td>TiO$_2$ (titanium dioxide)</td>
<td>1.11</td>
<td>1.17</td>
</tr>
<tr>
<td>Cr$_2$O$_3$ (chromium trioxide)</td>
<td>nd</td>
<td>0.01</td>
</tr>
<tr>
<td>Fe$_2$O$_3$ (iron oxide)</td>
<td>5.99</td>
<td>9.00</td>
</tr>
<tr>
<td>MnO$_2$ (manganese dioxide)</td>
<td>nd</td>
<td>0.14</td>
</tr>
<tr>
<td>LOI (loss on ignition)</td>
<td>7.55</td>
<td>8.71</td>
</tr>
</tbody>
</table>

nd = not determined

1.2.2 Recycled plasterboard

Recycled plasterboard samples were obtained from Roy Hatfield Ltd and Atritor Ltd. Table 3 shows the chemical analysis of the recycled plasterboard supplied by Roy Hatfield Ltd for the laboratory and production-scale trials.

Table 3 Chemical analysis of recycled plasterboard from Roy Hatfield Ltd

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O</td>
<td>2.4</td>
</tr>
<tr>
<td>MgO</td>
<td>0.7</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>2.5</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>5.8</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>47.6</td>
</tr>
<tr>
<td>CaO</td>
<td>40.3</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.7</td>
</tr>
</tbody>
</table>

2.0 Development work on the recycled plasterboard–clay mix

The following samples were processed:

- extruded bars (Etruria Marl and Keuper Marl bodies); and
- pressed briquettes (Etruria Marl only – the Keuper Marl products could not be pressed consistently under laboratory conditions).

The clays were mixed and soured (stored in a damp state) with the proportions of recycled plasterboard shown in Table 4, i.e. three test mixes and a control containing 0% recycled plasterboard.
The various mixed bodies were tempered with water until a consistent ‘workable’ body mix was produced. This was measured using a ‘ball drop’ technique where a standard weight ball falling over a standard height makes an indentation on a clay body of 2.54–3.05 mm. Between these levels of plasticity, the body is suitable for extrusion. The moisture content of the body was calculated based on weight loss when dried at 105°C for 24 hours.

The extruded bars were produced from a die with an aperture of 35 × 25 mm and cut to length (127 mm) using a wire cutter. The briquettes were formed using a hydraulic press having nominal mould dimensions of 75 × 35 × 25 mm.

The extruded bars and pressed briquettes were dried for 24 hours at four different temperatures – ambient (23°C), 100°C, 150°C and 200°C.

The linear shrinkage from wet to dry following drying was measured and the percentage of linear shrinkage calculated and recorded based on the wet length.

After drying, the extruded bars and briquettes were transferred to a conditioning tank consisting of a sealed tank with a mesh platform over water. This arrangement allowed the bars and briquettes to be kept out of contact with the water while maintaining the humidity in the tank at a relative humidity (RH) >80% so as to accelerate any rehydration of anhydrite (if present) to the gypsum form.

Following this conditioning process, the bars and briquettes were tested for change in length (expansion) based on the linear change from dry to ‘conditioned’. The linear expansion percentage was calculated on a dry length basis.

The extruded bars were subsequently tested for flexural strength and a modulus of rupture (MOR) was calculated.

### 2.1.1 Results of laboratory trials

The results for the Etruria Marl body (pressed briquettes and extruded bars) at the different drying temperatures are shown in Tables 5 and 6 respectively.

The results for the Keuper Marl body (extruded bars only) are shown in Table 7.

<table>
<thead>
<tr>
<th>Recycled plasterboard (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
</tr>
</tbody>
</table>
### Table 5 Results of laboratory trials with pressed briquettes containing Etruria Marl and recycled plasterboard

<table>
<thead>
<tr>
<th>Drying temperature</th>
<th>Moisture content (%)</th>
<th>Linear shrinkages (wet–dry): % of wet length</th>
<th>Hydrated expansion: % expansion against dry length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23°C</td>
<td>100°C</td>
<td>150°C</td>
</tr>
<tr>
<td>Control</td>
<td>19.2</td>
<td>5.1</td>
<td>4.5</td>
</tr>
<tr>
<td>25% recycled plasterboard</td>
<td>22.9</td>
<td>5.7</td>
<td>4.9</td>
</tr>
<tr>
<td>50% recycled plasterboard</td>
<td>26.6</td>
<td>6.3</td>
<td>5.2</td>
</tr>
<tr>
<td>75% recycled plasterboard</td>
<td>35.2</td>
<td>4.6</td>
<td>3.1</td>
</tr>
</tbody>
</table>

### Table 6 Results of laboratory trials with extruded bars containing Etruria Marl and recycled plasterboard

<table>
<thead>
<tr>
<th>Curing temperature (°C)</th>
<th>Moisture content (%)</th>
<th>Linear shrinkages (wet–dry): % of wet length</th>
<th>Hydrated expansion: % expansion against dry length</th>
<th>MOR (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Control</td>
<td>19.8</td>
<td>5.6</td>
<td>4.5</td>
<td>5.4</td>
</tr>
<tr>
<td>25% recycled plasterboard</td>
<td>22.0</td>
<td>6.0</td>
<td>4.7</td>
<td>5.5</td>
</tr>
<tr>
<td>50% recycled plasterboard</td>
<td>26.4</td>
<td>7.3</td>
<td>6.1</td>
<td>6.9</td>
</tr>
<tr>
<td>75% recycled plasterboard</td>
<td>29.4</td>
<td>7.6</td>
<td>7.1</td>
<td>6.9</td>
</tr>
</tbody>
</table>

### Table 7 Results of laboratory trials with extruded bars containing Keuper Marl and recycled plasterboard

<table>
<thead>
<tr>
<th>Curing temperature (°C)</th>
<th>Moisture content (%)</th>
<th>Linear shrinkages (wet–dry): % of wet length</th>
<th>Hydrated expansion: % expansion against dry length</th>
<th>MOR (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>Control</td>
<td>16.0</td>
<td>4.4</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>25% recycled plasterboard</td>
<td>17.2</td>
<td>4.4</td>
<td>4.0</td>
<td>3.8</td>
</tr>
<tr>
<td>50% recycled plasterboard</td>
<td>19.3</td>
<td>4.6</td>
<td>4.7</td>
<td>4.2</td>
</tr>
<tr>
<td>75% recycled plasterboard</td>
<td>22.9</td>
<td>3.2</td>
<td>3.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>
2.1.2 Recommendation
An addition of 50% recycled plasterboard to both the Keuper Marl (Hanson Red Bank) and the Etruria Marl (Baggeridge) was recommended for the production-scale trials. This addition rate provided a high recycled content without affecting the ceramic properties of the resulting product.

The addition of 75% recycled plasterboard resulted in some ‘dog-earing’ of the product.¹

The results in Tables 6 and 7 with the extruded bars suggest that the addition of recycled plasterboard to the extruded clay samples tended to increase the modulus of rupture.

3.0 Benchmarking and design of block products for the trial
Suitable benchmark products from which a gypsum–clay composite product could be designed and developed were provided by a clay–fibre block (Karphosit) and a gypsum block (Promonta). Both these blocks are sold as sustainable block products and are used for internal non-load bearing block applications. The characteristics of these products are compared in Table 8 with the target design features developed for the gypsum–clay product.

Promonta blocks are distributed by the NBS Group whereas Karphosit blocks are distributed through a number of eco-builders merchants. Both products are imported into the UK, thus increasing the delivered price and their environmental impact in terms of their ‘transport miles’. The Promonta (gypsum block) is understood to have a larger share of this part of the market than the Karphosit (clay–fibre block).

The project’s brick partner companies have different clay and processing techniques, and use a different design of extruder to manufacture their brick products. This is due to the nature of the clays processed and the format of the brick produced. As the block products are larger than traditional brick products, it is necessary to change the cut length of the extruded column and the die design to:

- produce a ‘tongue and groove’ structure; and
- enable a larger block dimension to be produced.

The block designs developed at Hanson Red Brick and Baggeridge Brick are described below. Following the extrusion process (see section 6.2), the gypsum–clay blocks were dried and packaged ready for despatch. The blocks were not fired.

¹ Figure 27 in section 6 shows an example of ‘dog-earing’.
Table 8 Benchmarking of Promonta versus Karphosit blocks and target design features of the plasterboard-clay composite block

<table>
<thead>
<tr>
<th>Material type</th>
<th>Clay–fibre block</th>
<th>Gypsum block</th>
<th>Gypsum–clay block</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product name</strong></td>
<td>Karphosit</td>
<td>Promonta</td>
<td>Branding to be developed</td>
</tr>
<tr>
<td><strong>Product variations</strong></td>
<td>One block type only</td>
<td>Normal (white) Hydro (blue) Heavy (pink) Acoustic Small/lightweight – 18 kg block</td>
<td>A number of alternatives could be developed.</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>Two tongue and groove sides – one short, one long</td>
<td>Two tongue and groove sides – one short, one long</td>
<td>Extrusion technique will limit the tongue and groove to one dimension only unless an additional rebating technique is used.</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td>Rough</td>
<td>Smooth</td>
<td></td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>250 × 500 × 100 mm</td>
<td>Normal: 667 × 501 thickness 50,60,70,100 450 × 501 thickness 100 Heavy: 640 × 501 thickness 50,60,70 450 × 501 thickness 70,100 Promhydro: 667 × 501 thickness 50,60,70,100 450 × 501 thickness 100</td>
<td>440 × 220 × (100/110)</td>
</tr>
<tr>
<td><strong>Weight of block</strong></td>
<td>12.5 kg</td>
<td>100 mm = 32 kg – partition wall 80 mm = 26 kg – partition wall 70 mm = 22 kg – partition wall 60 mm = 19 kg – inner skin 50 mm = 16 kg – inner skin [667 × 501 block format]</td>
<td>15–18 kg</td>
</tr>
<tr>
<td>Material type</td>
<td>Clay–fibre block</td>
<td>Gypsum block</td>
<td>Gypsum–clay block</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------------</td>
<td>--------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>900–950</td>
<td>Normal and Promhydro: 950</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy: 1,250</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity (W/m.K)</td>
<td>0.14</td>
<td>Normal: 0.35</td>
<td>To test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heavy: 0.52</td>
<td></td>
</tr>
<tr>
<td>Compressive strength (N/mm²)</td>
<td>2.3</td>
<td>Minimum of 5</td>
<td>3.5–5.0</td>
</tr>
<tr>
<td>Acoustic performance</td>
<td>45 dB (with plaster coat)</td>
<td>41 dB (950–1,000 kg/m³ 100 mm block solid wall)</td>
<td>45 dB</td>
</tr>
<tr>
<td>Moisture absorbance kg/m².h</td>
<td>3.3</td>
<td></td>
<td>To test</td>
</tr>
<tr>
<td>Diffusion resistance, u</td>
<td>4–6</td>
<td></td>
<td>To test</td>
</tr>
<tr>
<td>Wall weight (kg/m²) of 100 mm</td>
<td>86</td>
<td>98</td>
<td>Calculate on eventual weight of blocks</td>
</tr>
<tr>
<td>block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adhesive/ mortar system</td>
<td>Clay/fibre? – thin bed adhesive system</td>
<td>Gypsum-based plus bonding retardant and additives – thin bed adhesive system</td>
<td>Clay-based mortar – probably based on sodium silicate system</td>
</tr>
<tr>
<td>Plaster system</td>
<td>Clay</td>
<td>Promolys or Superpromontine – gypsum-based finishing plaster</td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay–gypsum</td>
<td>Gypsum based</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>B2 F90 90 minutes</td>
<td>Class O</td>
<td>Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Test data indicate that a wall built from 70 mm blocks would achieve a three-hour fire resistance and a wall built from 100 mm blocks would achieve a four-hour resistance.</td>
<td></td>
</tr>
<tr>
<td>Impact resistance</td>
<td>35 kg (point load)</td>
<td>30 kg sandbag: a partition wall of gypsum blocks of density 950 kg/m³ and 70 mm thickness gave the following results – no damage or breakthrough for energy levels equivalent to 60, 120, 180 and 240 joules. When tested to a hard body impact equivalent to an energy level of 10 joules, there was no breakthrough.</td>
<td>Test</td>
</tr>
<tr>
<td>Wetting expansion</td>
<td>?</td>
<td>10.6 \times 10^{-5}</td>
<td>Test</td>
</tr>
<tr>
<td>Wall mounting fixings</td>
<td>?</td>
<td>Not greater than 15 kg (5 kg per suspension point)</td>
<td>Test – arrangements are in place for testing via Rawl fixings</td>
</tr>
<tr>
<td>Applications</td>
<td>Applications: front wall and partition wall in dwellings, flats, offices, hotels, hospitals, rest homes, etc.</td>
<td>Applications: front wall and partition wall in dwellings, flats, offices, hotels, hospitals, rest homes, etc.</td>
<td>Partition walling system</td>
</tr>
</tbody>
</table>
3.1 Block design at Hanson Red Bank

A block design for Hanson Red Bank was developed to produce an extruded and perforated dried block with an approximate dimension of $440 \times 220 \times 120$ mm. Hanson Red Bank has two types of extruder:

- vertical - for small production runs of complex shapes or for small-scale trials; and
- horizontal - for standard shaped products and larger production runs.

Two die designs therefore had to be developed for the horizontal (Figure 1) and vertical (Figure 2) extrusion processes at Hanson Red Bank.
The die for the vertical extruder at Hanson Red Bank was manufactured internally (Figure 3) and used for initial trials extruding gypsum-clay blocks (see section 6.2.3); Figure 4 shows the design specification for this die. The die for the horizontal extruder was manufactured in accordance with the specification shown in Figure 5. The final horizontal die is shown in Figure 28 (see section 6.2.4).

**Figure 3** Completed die for the Hanson Red Bank vertical extruder

**Figure 4** Gypsum-clay block die design for vertical extrusion at Red Bank

Hanson Red Bank Unfired Plasterboard - Clay Block - Die for vertical extrusion

- Allows for 4% shrinkage to overall size 440 x 120 x 220 mm
- Cut off length 229 mm
3.2 Block design at Baggeridge Brick

A smaller block unit was developed for use at Baggeridge as the extruder it uses for brick manufacture is set up for smaller units. A block dimension of $300 \times 220 \times 120$ mm was proposed. However, production constraints unfortunately made it impossible to carry out any trials at Baggeridge involving recycled plasterboard and the design was not taken forward.

A ‘tongue and groove’ rebated system was not developed for the extruded product at Baggeridge.

4.0 Waste plasterboard processing

The clay brick industry adds a number of industrial minerals to the manufacturing process. These are added in bulk at various rates. Thus the crushed plasterboard material could be added using traditional techniques (e.g. powder handling technology or box feeder and bucket blending operations).

Some processing was required before recycled plasterboard could be used as a feedstock in the manufacture of the gypsum-clay blocks.

One potential issue in the manufacture of extruded block products is the inclusion of fibres from the backing paper of the plasterboard. This is because the fibres may accumulate on the cutting wires used to cut the extruded blocks into the required block length. As long as the fibres are short enough, this was considered unlikely to be a major issue and was assessed as part of the production-scale trials.

If the production process is flexible enough to accommodate a high level of backing paper within the processed plasterboard this may offer:

- product advantages, e.g. improved flexural strength and fixing properties; and
- process advantages, e.g. only a simple and cheap crushing and shredding process would be required to develop a feedstock that can be used in the manufacture of a gypsum-clay block.
4.1 Processing at Roy Hatfield Ltd

The recycling facility at Rotherham (Figures 6 and 7) processes waste plasterboard from a number of industrial, commercial and domestic clients.

Recycling involves a series of shredding, crushing and air-separation processes (Figure 8) to produce a 10–15 mm material. Some of the samples from the initial production had a high residual paper content, but further engineering refinements have reduced this to <1%.

Plasterboard from the Roy Hatfield process was used for laboratory and initial production-scale trials (see section 6.2).
4.2 Processing at Atritor Ltd

Atritor Ltd has developed a ‘turbo separator’ (Figure 9) for the processing and separation of lightweight contaminants within a number of waste streams including:
- separation of paper and gypsum in plasterboard for waste gypsum recovery;
- steel from pyrolysed tyres; and
- foodstuffs from packaging.

The materials to be separated are introduced into the processing unit via a flanged inlet before being cycled through an agitator. The variable speed, together with the design of the beater blades and breaker bars, separates the component parts of the incoming material. The processed materials are routed through a central discharge where the product is screened out. Various screens can be used to adjust the product size and consistency. The lightweight components (e.g. paper) continue through the cylinder before being discharged for disposal or recycling.
Trials were carried out during December 2006 when a test rig (Figure 10) was used to process waste plasterboard into a ground gypsum component and a paper fraction (Figure 11).

**Figure 9** Blade system and schematic drawing of Atritor's turbo separator

**Figure 10** Atritor test rig used for plasterboard processing trials

The Atritor material was not actually used to produce gypsum-clay blocks as it would not have been possible to produce enough processed material by this method for the production-scale trials. However, the trials at Atritor demonstrated that its system was capable of processing waste plasterboard to generate a gypsum fraction with a reduced proportion of backing paper in the resulting product.

The main reason for carrying out the trials using the Atritor turbo separator was to evaluate the process to see if the technology could be used at the 'front end' of a brick making process to produce a plasterboard material suitable for use as a raw material within a brickworks.

The processed plasterboard (<15 mm) was comparable with the processed plasterboard received from Hanson Red Bank during the production-scale trials and would therefore be suitable as a feedstock in the production of gypsum-clay blocks. Processing of waste plasterboard using the Atritor system could be carried out at the block factory or at a satellite processing operation located near the source of plasterboard waste (e.g. waste transfer station).
5.0 Addition of processed plasterboard to the block making process

5.1 Use of a bulk bag discharge unit

A number of methods were available for introducing the processed plasterboard to the clay block making processes including:

- bucket mixing with clay with subsequent passage through a box feeder arrangement into the normal grinding process (dry pan or wet pan processing);
- separate clay/processed plasterboard box feeder arrangement; and
- addition of processed plasterboard addition via a silo feed.

The last process was simulated in a small-scale trial at the Hanson Red Bank brickworks at Measham using a bulk bag discharge unit (BBDU) manufactured by Spiroflow (www.spiroflow.com). This technology has proved successful with a number of mineral powders, including recycled glass. The successful feeding of a bulk bag of processed plasterboard (5–10 mm) through the BBDU demonstrated that the technology offered a method of controlled addition of processed plasterboard to the clay block making process (Figure 12).

The addition rate achievable by a BBDU depends on:
the type of unit used; and
the feed rate of the clay process which the plasterboard discharge enters.

5.2 Use of a front-end loader and bucket blending technique
Following a review of the feed process used in the initial trials at Hanson Red Bank, addition of plasterboard and blending with clay using a bucket-loading shovel was recommended as higher additions (+50%) of plasterboard could be achieved through a full-scale production process.

The plasterboard and clay were mixed using the front-end loader (Figure 13) within a ‘mixing shed’ and fed into the dry grinding process via a box feeder arrangement. Mixing was carried out on a 50 : 50 plasterboard : clay (volume basis).

6.0 Trials of gypsum–clay block production
There are two potential techniques available for the manufacture of a gypsum–clay block:
- extrusion; and
- pressing.

Extrusion is a well-established traditional technique for the manufacture of brick products and thus has considerable potential for the manufacture of a gypsum–clay block. Water is usually added to facilitate extrusion of a clay body; a typical moisture content for extrusion is ~15–18% (dry basis).

The extrusion process provides a means of developing a dense, high-strength block product that could be produced on a commercial scale. Extrusion can be achieved through a number of different machine types, though these can be categorised into horizontal (high throughput) and vertical (low throughput). Both production techniques were examined in the trials (see section 6.2).

Pressing of a relatively dry plasterboard–clay mix (typical moisture content of 5–10%) provides an alternative process by which a gypsum–clay block could be manufactured. Few ‘dust pressing’ operations are available in the UK brick industry and these are typically restricted to standard size brick dimensions (215 × 102.5 × 65 mm).

Compressed earth block machines (CEBMs) are used in a number of developing countries to process locally sourced materials to produce a clay block for use in internal and external product applications. A number of additives are used to improve the performance characteristics of the block including various fibres (e.g. straw), sand, lime, etc. Blocks produced for external applications and for structural properties are normally enhanced by the use of cement; these are referred to as cement stabilised clay blocks (CSCBs). The potential of one pressing technology to manufacture a gypsum–clay block was examined as part of the project (see section 6.1).
6.1 Pressing using a compressed earth block machine
Compressed earth block machines (CEBMs) have been developed to produce clay blocks for use in a number of construction applications – particularly in developing countries where there is a need for a transportable mechanical process to produce compressed earth block from earth on the actual building site. Figure 14 shows a typical CEBM available from Oskam V/F (www.oskam-vf.com) based at Lekkerkerk in the Netherlands.

![Typical CEBM with automatic pressing machine (Source: Oskam V/F)](image)

Although portability may provide an advantage for processing waste plasterboard from a large construction site and for mixing with clay to produce a gypsum–clay block, the main areas of interest at this stage were:
- the pressing technology; and
- the previous use to produce comparable clay/earth blocks for sustainable market applications.

CEBMs are relatively simple machines consisting of a clay feeding mechanism, a pulveriser and a mixer (where a number of other materials such as straw, sand, etc. can be added), followed by an automatic pressing machine.

Figures 15 and 16 show schematic diagrams of a typical CEBM from Oskam V/F.

The typical properties of a compressed earth block made using this technology are given in Table 9.

![Table 9 Typical physical and mechanical properties of clay blocks produced using a CEBM (Source: Oskam V/F technical literature)](table)

### Table 9

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity ($\rho$)</td>
<td>Dimensions 29.5 x 14 x 9 cm</td>
</tr>
<tr>
<td>Thermal conductivity ($\lambda$)</td>
<td>Weight 7.5 kg</td>
</tr>
<tr>
<td>Warmth resistance (R) of wall of 40 cm</td>
<td>Compressive strength ($\sigma$) 5-6 N/mm²</td>
</tr>
<tr>
<td>Damp diffusion ($\mu$)</td>
<td>Stabilised blocks with 4-6% 8-18 N/mm²</td>
</tr>
<tr>
<td>Warmth accumulation capacity (Cw) (A massive wall of 40 cm thickness gives a thermic reduction of 10% and a delay of ~10 hours)</td>
<td>Sound insulation of 40 cm wall 56 dB</td>
</tr>
</tbody>
</table>
A visit to Oskam’s demonstration unit was arranged to view the production of clay blocks and to assess the technology’s potential for the production of a gypsum-clay block.
Clay blocks and cement-stabilised clay blocks were produced during the trials using a CEBM deploying a pressure of 5.0 MPa (Figures 17–19).

**Figure 17** Additive feed into the mixer section of the CEBM

**Figure 18** Clay feed system (top left) and automatic clay block press
Use of a CEBM was of interest to the project team as an alternative to extrusion and the technical information provided (on clay only) appeared promising for a number of construction product applications. Plasterboard could be introduced into the process at a controlled rate and a composite product developed. The opportunity to develop a cement-stabilised product for structural applications was also of interest, as well as the option to produce a fully profiled interlocking block product, which might reduce the use of mortar during block installation.

The unit demonstrated by Oskam was a small portable machine producing 360 blocks/hour (standard block dimensions of 295 × 140 × 110/90/70 mm), equivalent to 10.7 m$^3$ wall or 23 tonnes/day. This technology could easily be scaled up to the volumes achieved within a traditional concrete block plant. An off-the-shelf CEBM from Oskam would have an estimated total annual output of >6,000 tonnes. This is equivalent to 3,000 m$^3$ of total blocks which, at a 50% volume addition, would utilise 1,500 m$^3$/year of recycled plasterboard.

6.2 Extrusion trials

Production constraints meant that trials could not be carried out at Baggeridge Brick during the timescale of the project. Some clay blocks were produced but there was no opportunity to carry out trials incorporating recycled plasterboard.

However, a wide range of trials was carried out at Hanson Red Bank. These trials covered horizontal and vertical extrusion as well as the manufacture of 120 mm and 100 mm block products.
The vertical extrusion trials (see section 6.2.3) at Hanson Red Bank were performed before the larger-scale horizontal extrusion trials (see section 6.2.4) because they provided an opportunity to produce a small number of gypsum–clay blocks without disrupting the horizontal extrusion plant, which is normally fully committed to the production of a wide range of terracotta products. The vertical extruder trials also allowed the project team to assess the ease of processing the plasterboard-clay mix and to give Hanson Red Bank confidence to go ahead with a larger scale, more disruptive trial on the horizontal extruder. Another reason for the vertical extruder trial was to produce a product with a different block profile.

Both the vertical and horizontal extrusion trials required the production of about the same amount of plasterboard-clay blend. Although fewer block products were produced in the vertical extrusion trial compared with the horizontal extrusion trial (the former is more labour-intensive), it was necessary to blend a large batch of clay and plasterboard in order to deliver a known mix to the plant. This mix was stored in a silo prior to the vertical extrusion trial. Some of the surplus processed material from the trial was bagged for future development work.

### 6.2.1 Initial trial to produce 100% clay blocks

An initial trial was performed with a red clay body (no plasterboard addition) to evaluate the physical aspects of large format block manufacture. This trial was carried out on the Hanson Red Bank horizontal extruder (see section 3.1). The special die for the horizontal extruder was not available at the time of the trial to produce a profiled block so a straight-edged die was used to manufacture the blocks from 100% clay.

The trial was successful in producing a clay block product, giving the team confidence to proceed with trials on the vertical and horizontal extruder with recycled plasterboard.

Figures 21 and 22 show the production of clay blocks using the horizontal extruder. The block product was then conveyed and set on stillages prior to drying.
6.2.2 Preparation of the plasterboard–clay mix

The processed plasterboard supplied by Roy Hatfield Ltd (see section 4.1) was bucket blended with the Keuper Marl clay on a 50 : 50 volume basis. The plasterboard–clay mix (Figure 23) was then dry ground using a hammer mill process to grind and screen the blend to particles of <2.0 mm. A particle size analysis of the resulting blend was carried out (Figure 24) as well as a chemical analysis (Tables 10 and 11). Analysis also revealed that the plasterboard mix contained 0.8% carbon and 4.5% sulphur.

Figure 23 Bulk bag containing a representative sample of the processed 50 : 50 plasterboard–clay mix

Figure 24 Particle size analysis of the 50 : 50 plasterboard-clay mix
Table 10 Chemical analysis of the 50 : 50 plasterboard–clay mix (T2905F06 Keuper/plasterboard mix)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O (sodium oxide)</td>
<td>0.6</td>
</tr>
<tr>
<td>MgO (magnesium oxide)</td>
<td>3.6</td>
</tr>
<tr>
<td>Al$_2$O$_3$ (aluminium oxide)</td>
<td>9.5</td>
</tr>
<tr>
<td>SiO$_2$ (silicon dioxide)</td>
<td>49.8</td>
</tr>
<tr>
<td>SO$_3$ (sulphur trioxide)</td>
<td>13.7</td>
</tr>
<tr>
<td>K$_2$O (potassium oxide)</td>
<td>3.4</td>
</tr>
<tr>
<td>CaO (calcium oxide)</td>
<td>13.9</td>
</tr>
<tr>
<td>TiO$_2$ (titanium dioxide)</td>
<td>0.5</td>
</tr>
<tr>
<td>Fe$_2$O$_3$ (iron oxide)</td>
<td>5.0</td>
</tr>
<tr>
<td>LOI (loss on ignition)</td>
<td>9.0</td>
</tr>
<tr>
<td>Total</td>
<td>99.9</td>
</tr>
</tbody>
</table>

Table 11 Screening analysis (trace) of the 50 : 50 plasterboard–clay mix (T2905F06 Keuper/plasterboard mix)

<table>
<thead>
<tr>
<th>Element</th>
<th>Amount (μg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (phosphorous)</td>
<td>100</td>
</tr>
<tr>
<td>Cl (chlorine)</td>
<td>241</td>
</tr>
<tr>
<td>V (vanadium)</td>
<td>82</td>
</tr>
<tr>
<td>Cr (chromium)</td>
<td>65</td>
</tr>
<tr>
<td>Mn (manganese)</td>
<td>629</td>
</tr>
<tr>
<td>Ni (nickel)</td>
<td>30</td>
</tr>
<tr>
<td>Cu (copper)</td>
<td>25</td>
</tr>
<tr>
<td>Zn (zinc)</td>
<td>129</td>
</tr>
<tr>
<td>Ga (gallium)</td>
<td>16</td>
</tr>
<tr>
<td>Rb (rubidium)</td>
<td>108</td>
</tr>
<tr>
<td>Sr (strontium)</td>
<td>207</td>
</tr>
<tr>
<td>Y (yttrium)</td>
<td>24</td>
</tr>
<tr>
<td>Zr (zirconium)</td>
<td>271</td>
</tr>
<tr>
<td>Nb (niobium)</td>
<td>12</td>
</tr>
<tr>
<td>Sb (antimony)</td>
<td>2</td>
</tr>
<tr>
<td>Cs (caesium)</td>
<td>29</td>
</tr>
<tr>
<td>Ba (barium)</td>
<td>501</td>
</tr>
<tr>
<td>La (lanthanum)</td>
<td>77</td>
</tr>
<tr>
<td>Ce (cerium)</td>
<td>139</td>
</tr>
<tr>
<td>Pb (lead)</td>
<td>27</td>
</tr>
<tr>
<td>Th (thorium)</td>
<td>14</td>
</tr>
<tr>
<td>U (uranium)</td>
<td>10</td>
</tr>
</tbody>
</table>

No processing problems were observed during the grinding process and the grinding was successful in producing a fine, free-flowing plasterboard–clay mix (Figure 23).
6.2.3 Vertical extrusion of gypsum–clay blocks

The plasterboard–clay mix was mixed with water in a double-shafted mixer before being extruded through the profiled die (Figure 3) on the vertical extruder. Figures 25 and 27 show the blocks in production and the vertical extrusion process respectively.

There was some slight ‘dog-earing’ (Figure 26) on the extruded column but this was thought to be associated with:

- moisture control of the supplied mix;
- lack of die lubrication; and
- the stop-start nature of the vertical extrusion process (this is not a continuous extrusion process as each block has to be extruded and removed by hand).

Use of the horizontal extruder (see section 6.2.4) was expected to rectify this fault.

Following the extrusion process, the blocks were dried according to the standard brick/terracotta drying schedule (three days at 70–80°C). In addition, a small batch was dried to 150°C in a batch kiln (i.e. the temperature at which gypsum decomposes to anhydrite). This was to test the effects of the presence of any anhydrite in the blocks made from the 50 : 50 plasterboard–clay mix.
The average compressive strength of the standard (low temperature) dried blocks was 3.5 N/mm². Compressive strength testing of the blocks dried at 150°C blocks gave similar compressive strength results.

Figure 26 Gypsum-clay blocks being produced on the vertical extruder
6.2.4 Horizontal extrusion of gypsum–clay blocks

Large-scale trials using the horizontal extruder were carried out at Hanson Red Bank to:

- produce the gypsum–clay blocks for accreditation testing; and
- supply products for a number of demonstration projects.

The horizontal extruder allows more efficient production of the gypsum–clay blocks because it is set up to produce block products at a greater throughput than the vertical extruder. The horizontal extrusion trials were carried out at the same scale as a normal production run during a typical shift on the plant, which is rated at >20 tonnes/hour of product.

The die for the horizontal extruder detailed in the specification shown in Figure 2 was made for the extruder in advance of the trials. This die (Figure 28) produced a profiled block on the bed face of the product.

---

**Figure 28** Completed die for the horizontal extruder at Hanson Red Bank

The processed plasterboard was provided by Roy Hatfield Ltd (see section 4.1). It was delivered to the factory in a 30-tonne artic vehicle and tipped into a clay storage shed (Figure 29). It was subsequently bucket blended using a front-end loading machine and fed into the processing plant by means of a box-feeder (Figure 30).

---

**Figure 29** Processed plasterboard from Roy Hatfield Ltd in clay storage shed
Before the plasterboard-clay mix was fed via a conveyor system into the grinding plant, it passed under two magnetic separators (Figure 31) where any metallic contaminants are removed.

The processed plasterboard used in the trial contained a number of metallic contaminants - mainly plasterboard nails (Figure 32) - but these were effectively removed by the magnetic separators. This information was fed back to the processed plasterboard supplier (Roy Hatfield Ltd) and additional magnetic separators have now been installed at the supplier’s plant to minimise the metallic contaminants within the product.
The clay-gypsum mix was then fed into a hammer mill (Figure 33) and through screens to produce a crushed material with particles <3 mm. The crushed clay-gypsum was then stored in a silo (Figure 34) before being fed into a double-shafted mixer where water was added and finally into the extruder. Figure 35 shows the mixer and extruder.

Moisture control at the mixer was critical to ensure a consistent feed was fed to the extruder. A close-up of the mixer is shown in Figure 36 and Figure 37 shows the extruded column of gypsum-clay.
**Figure 34** Clay silo and conveyor feed system

**Figure 35** Mixer and extruder

**Figure 36** Close-up of mixer
As seen in the vertical extruder trial (see Figure 27), there were some initial issues with moisture control that led to ‘dog-earing’ on the extruded column (Figure 38).

However, these were soon resolved and the column extruded well, with the column capable of being cut through with a wire cutter to produce block products (Figure 39). There was no significant build-up of fibres from the paper within the processed plasterboard on the wire cutter as had initially been expected (see section 4). This therefore did not affect the quality of the cutting process.

Figure 40 shows the cut blocks on the conveyor.
The clay-gypsum blocks were lifted manually from the conveyor and placed on drier racks (Figures 41 and 42).

During the lifting process some blocks bent slightly, resulting in some misshapen (bent) block products following drying. This distortion could be eliminated or reduced by utilising a robot setting and/or the extrusion of a lighter block. The latter option could be easily achieved by extruding a 100 mm thick block which would reduce the weight of the extruded block to ~14–15 kg (compared with ~18 kg for the 120 mm block). This ties in with customer feedback obtained from the demonstration trials and at the Ecobuild 2007 exhibition (see section 8.3) requesting a 100 mm block product.

The clay-gypsum blocks were allowed to air-dry in a holding chamber (Figure 43) for 1–2 days prior to forced drying at ~60–80°C.
Use of recycled plasterboard in unfired clay-gypsum blocks

Figure 41 Gypsum-clay blocks set out manually on drier pallets

Figure 42 Close-up of gypsum-clay blocks set on pallets

Figure 43 Clay-plasterboard blocks in holding chamber
The drying process resulted in a block with a moisture content of ~3–5% and a compressive strength of ~3 N/mm². After drying, the blocks were shrink-wrapped on pallets (Figure 44).

Figure 44 Shrink-wrapped and palletised blocks

7.0 Development of mortar/plaster system for the clay-gypsum block

A number of mortars were examined to establish the most appropriate mortar system to use with the clay-gypsum blocks. A traditional cement: sand mortar was also assessed in one demonstration wall (see section 8.5), but this proved to be ineffective in bonding the blocks and resulted in cracking of the blocks on drying.

A mortar system based on clay, silica sand and sodium silicate was found to be the most appropriate mortar to use to bind the blocks together. A thin joint mortar system could be applied to the bed of the blocks as shown in Figure 45. Such a mortar system can be applied using a cartridge gun or a trowel.

Additional work to assess the developed mortar system more fully is underway at Bath University. The work includes investigating mortar strength over a period of time.
8.0 Demonstration and evaluation trials

8.1 Demonstration wall at Hanson Red Bank
A demonstration wall was constructed at the brickworks at Hanson Red Bank, Measham, using the mortar system described in section 7. Figure 45 shows the mortar application to this wall.

The sodium silicate based mortar produced a very hard bond between the blocks and the wall was constructed using a thin joint mortar system applied using a cartridge gun system (Figure 46).

The developed joint between the mortar and the profiled block is shown in Figure 47. The final block wall is shown in Figure 48.
Figure 46 Sodium silicate based mortar bead applied using a cartridge method

Figure 47 Joint developed by the mortar and block profile
8.2 Demonstration wall at Green Clay Limited (Natural Building Technologies)

Green Clay Ltd (a company majority owned by Natural Building Technologies) was commissioned by Akristos Ltd to assess the application issues with the current design of the gypsum–clay blocks, with particular reference to the block laying and plastering processes. Green Clay Ltd has technical and practical knowledge of block laying techniques and plastering obtained from its experience with conventional blockwork and with unfired clay products.

The main emphasis of the work was to gain an understanding of the practical application issues likely to be experienced on UK construction sites. A professional bricklayer and plasterer were engaged with experience of mainstream construction sites and the use of unfired clay, lime and other specialist products.

The test methodology was determined partly by normal practices at UK sites, including common tools and methods of building.

A simple standard mesh pull-out test was also undertaken to ascertain the bonding of the different plasters to the blocks. The purpose of this testing was to provide feedback on plaster application to the blocks before decisions were made on the direction of further product development prior to further testing and then formal testing and accreditation.

8.2.1 Block laying

The bricklayer built a small section of staggered wall with two right-angled corners (Figure 49) using the ready mix clay–sodium silicate mortar provided. This involved:

- cutting the blocks using a number of common site tools;
- laying the mortar with common bricklaying tools (i.e. trowels, hammers, bolsters, angle grinders, masonry saw, etc.); and
- using levels and profiles to ensure the correct angles, uprightness and level standing of the blockwork.

Some basic testing was also undertaken as regards:

- chasing into the blocks (as would be required for electrics installation); and
- fixing into the blocks (as would be required for the hanging of shelves, etc.).

Again only common methods of chasing and fixing were tried.

The main conclusions from the block laying trials are described below.
Block size and shape
The blocks were all slightly curved along their length, which made it difficult to build a straight wall without continual adjustment in the perpendicular joints (Figure 50).

The curvature of the block was produced during the manufacturing process when the heavy ‘green’ (wet) block was lifted from the conveyor system onto the drying pallets (see section 6.2.4). This problem can be resolved by reducing the thickness of the block to a more manageable 100 mm unit, which reduces the overall weight of the block. Refinements to the extrusion process and moisture control would also help to reduce the curvature of the blocks. Robotic handling of the product from the conveyor would help to minimise product distortion.

The blocks were at their limit for weight. They were heavy and not particularly easy to handle. A reduction in product weight would be advantageous and could again be achieved by reducing the product thickness to 100 mm.

The profiles on the top and bottom of the blocks created difficulties for the bricklayer at corners where there was a staggered joint, as the profile on top of the block had to be removed. This was time-consuming and difficult. It also meant that extra mortar was required to fill the gap left between the flat top of the block and the grooved bottom of the block above (Figure 51). Ways of solving this problem include:

- making a corner ‘special’; or
partly removing the profiled section in the ‘green’ (wet) state to avoid having to perform the procedure during the wall construction process.

The blocks were extruded with holes along their length horizontally. This meant that more mortar was required on the perpendicular faces than on the profiled surfaces. This is a much more difficult situation as the blocks are heavy and mortar on perpendicular faces is more likely to slump or fall during application. There is also the high risk of mortar being wasted in the large horizontal holes and of mortar not being applied fully to these surfaces. The latter could effect acoustic and fire protection performance. This issue might be resolved by applying mortar using a cartridge type system.

Although the products could be extruded vertically, this will limit the production volumes that could be produced. Pressing the blocks could produce a product that is profiled on the perpendicular faces and on the bed face of the block – allowing thin mortar joints to be used on the connecting units. A thinner 100 mm block unit with smaller perforation holes will also be an advantage.

The current perforation design could become problematic at corners, doorways or other vertical junctions (Figure 52). They may also present problems for:
- plastering because of the need to fill these holes; and
- fixing door frames, etc. because of the likelihood of the fixing going into one of the holes or breaking out into a hole.

One solution is to produce solid (non-perforated) blocks for specific use in these design areas.

The width of the block (120 mm) is non-standard and will cause problems at doorways with conventional linings (135 mm). A 100 mm block would resolve this issue.

**Mortar**

The bond of the sodium silicate mortar with the blocks seemed good. It was possible to obtain a good bond with a relatively thin joint (3–5 mm).

The mortar was applied from the small tubs that were supplied. These can be quite sticky, making it difficult to apply. This problem might be resolved by using a cartridge system (as used in the Hanson Red Bank wall – see section 8.1).

There were also issues with filling joints fully. This problem arose because of the need to remove profiles at staggered corners and particularly because of the horizontal holes in all the perpendicular joints.
**Cutting**
Cutting the blocks using a hammer and bolster was successful, although there was a tendency for blocks less than 200 mm long to shatter unevenly.

Using an alligator saw created a fine dust. This issue would also arise with angle grinders and other fine mechanical tools.

**Chasing**
It was not possible to chase the blocks with a standard hammer and bolster. However, it was quite easy to chase the blocks with a twin blade angle grinder as is commonly used for chasing blockwork. Overall, it was not felt there were significant differences in chasing between the clay-gypsum blocks and standard concrete blocks.

**Fixing**
Both frame fixings and Rawl plug fixings were used without difficulty. Simple pull-out tests indicated that the fixings held well.

### 8.2.2 Plastering
A plasterer applied five different plasters in applications with and without primer, making 10 applications in total. The plasters selected were:
- Hardwall gypsum;
- bonding gypsum;
- lime plaster (BaumitBayosan RK38) - fat lime with pozzolanic additives;
- lime cement bonding plaster (BaumitBayosan MC55w) - fat and hydraulic lime with cement and bonding additives; and
- clay plaster (Claytec undercoat) - clays, silts and sands with chopped straw.

The primer was BaumitBayosan DG27 - a polyvinyl alcohol (PVA) based primer specially designed to allow good vapour permeability, while reducing capillary suction yet still providing a key for plasters.

All plaster samples had a fibre glass mesh embedded in the plaster, with 100 mm of mesh protruding unplastered from the top of the sample. The plasters were left to harden sufficiently (three days for the gypsum plasters; 10 days for all other plasters) before the mesh was pulled out. This gave an indication of the bond strength between plasters and blocks. Where the mesh pulled out of the plaster without pulling the plaster from the blocks, the plaster was considered as having a good bond with the substrate.

Figure 52 shows the mesh in a plaster sample after it has been pulled away from the plaster. Before the pull test, the mesh was 100 mm above the blockwork. This particular plaster test showed that the plaster was well bonded to the wall.
The results from the plastering trials can be summarised as follows:

- **Hardwall gypsum** (Figure 53). The Hardwall gypsum is the sample on the left. This side of the wall was without primer. Although the backside of the wall was primed, a similar failure occurred.

  ![Figure 53 Failure of Hardwall gypsum (left)](image)

- **Bonding gypsum** (Figure 54). The mesh pulled out adequately but, on further examination of the plaster, the whole area was slightly hollow and was easily pulled off. The bond was not adequate. Figure 54 shows the same side of the wall as in Figure 53 (illustrating the failure of the Hardwall gypsum). In Figure 53, the bonding was still on the wall after the mesh had been pulled out. But on tapping the plaster, it was discovered to be hollow in some places and was easily removed by hand in a large sheet which broke on hitting the ground (Figure 54). Overall, the primed surfaces performed slightly better than the unprimed surfaces as far as the gypsum products were concerned. In all other products, no difference was detected. Figure 55 shows the use of bonding gypsum (left) and Hardwall gypsum (right) on blocks treated with primer. Both became hollow and sections were easily removed by hand.

  ![Figure 54 Failure of bonding gypsum to hold plaster](image)
Lime plaster (RK38) (Figure 56). Good adhesion was achieved with this plaster. No hollow areas were detected and the plaster was impossible to remove by hand. There was no noticeable difference between primed and unprimed areas of wall. Figure 56 shows the plaster with the mesh half pulled out.

Lime cement bonding plaster (MC55w). Good adhesion was achieved. It was almost impossible to pull the mesh out of the plaster, and when this was achieved the bond of plaster to the blocks was still good. No hollowing occurred and it was not possible to remove the plaster from the blocks by hand. There was no noticeable difference between primed and unprimed areas of wall.

Clay plaster (Claytec undercoat) (Figure 57). Good adhesion was achieved. No hollowing of the plaster occurred and the plaster could only be removed by scraping although it is softer than gypsum, lime or cement products. Overall, the bond with the blocks was very good – both on the primed and unprimed sides of the wall. Figure 57 shows the clay undercoat plaster on the primed area of wall with mesh removed; on the floor can be seen the mesh and the fine plaster that came off the wall with it.
Conclusion
The results indicated that gypsum plasters can not be recommended as a finish to the blocks. This concurred with tests carried out on other clay blocks. But as the primed areas were slightly better than the unprimed areas, it was felt it might be worth investigating other primers and other methods of application (e.g. wet on wet). However, doubt may still remain about the effect of environmental conditions over time on the bond, particularly in areas where there may be large influxes of moisture into the block system. Considerably more research into the use of gypsum plasters over clay gypsum products will be necessary before the former can be specified with confidence.

The results also suggested that a solution with a lime, lime cement or clay plaster was probably the best choice. This backed up other work and experience where these plasters have been successful on other clay blocks.

It was felt that use of the lime cement bonding plaster was probably not necessary as it is a more expensive product. However, it would be worth testing site sand : lime cement mixes to see if they worked as they would be a cheaper solution.

8.3 Demonstration walls at Ecobuild 2007 and other events
Ecobuild 2007 was held at Earls Court from 27 February to 1 March 2007 and was attended by 13,404 visitors including architects, builders, consultants and developers. Figure 58 shows the visitor profile.

Akristos had a stand (Figure 59) at the event exhibiting the gypsum-clay blocks (under the Naterra™ branding) with 50% recycled plasterboard content.
The exhibition offered an opportunity to construct a demonstration wall to:
- highlight the technical properties of the gypsum-clay block; and
- attract potential customers for the product, a number of which have now started to purchase it.

Positive feedback was obtained at Ecobuild 2007 from visitors and other exhibitors, some of which could lead to new product sales. It has since been arranged to have a demonstration wall at the Ecobuild 2008 exhibition which will be at the Hanson stand and therefore this will have a higher profile.

A demonstration wall also featured at an event in March 2007 at The Forum, Norwich, where a number of potential customers viewed the product and the method of wall construction.

The gypsum-clay blocks were displayed at an event organised by the Carbon Innovation Exchange on 14 June 2007 at Olympia, London.

### 8.4 Demonstration walls at Springhill Farm, East Sussex

Approximately 2,000 blocks (120 mm thick) were supplied to a sustainable barn/office conversion near East Sussex designed by Nick Pople and constructed by Douch Partners Limited. The project consisted of a number of small office units constructed within an existing barn. This was a major project and the first full commercial use of such block products.

The blocks were not finished or covered with plaster. Instead they were simply waxed to give a smooth natural red clay lustre. This process produced a splash-resistant product.

Some trials were also carried out with a 100 mm thick block (~1,000 blocks were supplied). One office was constructed using these blocks. The products were much easier to handle (<15 kg) compared with the heavier 120 mm blocks. A specific production run and new die was manufactured for this trial. As well as being lighter, the 100 mm blocks did not show any significant bending during manufacture and drying.

Figures 60–64 show various stages in the construction process and final finished walls with the 120 mm blocks (Figure 62) and the 100 mm blocks (Figure 64).
Figure 60 Block cutting in the barn

Figure 61 Block masonry construction using the 120 mm blocks
Figure 62 Completed wall with wax finish – 120 mm thick blocks

Figure 63 Blockwork (100 mm thick blocks) covered to protect it from the rain

Figure 64 Completed 100 mm block wall with wax finish
8.5 Demonstration wall at an industrial unit, Stoke-on-Trent

A demonstration wall was constructed at an industrial unit in Stoke-on-Trent using a conventional sand : cement mortar (Figure 65). Previous laboratory work had indicated that the water within the sand : cement mortar would be quickly absorbed into the block matrix and this was evident on the blocks. This resulted in the development of a ‘drying front’ (Figure 66) around the edges of the block. This then caused cracking. However, it was a useful exercise to demonstrate that water-based mortars are not suitable for bonding the gypsum–clay blocks.

![Gypsum–clay blocks with and conventional sand : cement mortar](image1)

![Drying cracks developing where water absorbed into the block matrix](image2)

8.6 Demonstration walls and evaluation trails at Bath University

Tests on prototype gypsum–clay blocks were carried out in the laboratories of the Department of Architecture & Civil Engineering\(^2\) at Bath University on:

- compressive strength;
- flexural strength (including influence of moisture content);
- erosion and abrasion resistance; and
- dimensional consistency, including shrinkage and expansion.

The test results are summarised in Table 12.

\(^2\) Now the BRE Centre in Innovative Construction Materials
Table 12 Summary of test results at Bath University

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average normalised block compressive strength (at ambient moisture content)</td>
<td>3.5 N/mm²</td>
</tr>
<tr>
<td>Average block flexural strength (at ambient moisture content)</td>
<td>3.0 N/mm²</td>
</tr>
<tr>
<td>Average block dry density</td>
<td>1,717 kg/m³</td>
</tr>
<tr>
<td>Average flexural bond strength at 28 days</td>
<td>0.83 N/mm²</td>
</tr>
</tbody>
</table>

8.6.1 Dimensions
Block dimensions were determined by ruler, to the nearest millimetre, on six blocks selected randomly from the sample provided. The measurements were undertaken on blocks stored at the ambient laboratory conditions (20° C and 65% RH). The length was measured in four positions (along corner edges), the height at six positions (corners and mid length) and the width at six positions (corners and mid length). The results are outlined in Table 13.

Table 13 Block dimensions

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
<th>Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>439</td>
<td>219</td>
<td>119</td>
</tr>
<tr>
<td>2</td>
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<td>220</td>
<td>119</td>
</tr>
<tr>
<td>3</td>
<td>438</td>
<td>219</td>
<td>119</td>
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<td>4</td>
<td>438</td>
<td>219</td>
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<td>219</td>
<td>119</td>
</tr>
<tr>
<td>6</td>
<td>438</td>
<td>219</td>
<td>119</td>
</tr>
<tr>
<td>Average</td>
<td>438</td>
<td>219</td>
<td>119</td>
</tr>
</tbody>
</table>

8.6.2 Compressive strength
The compressive strength of the blocks was determined following, as much as possible, the provisions of BS EN 772-1: 2000 in which the uni-axial compressive strength (maximum load divided by cross-sectional area) is geometrically corrected to provide a normalised compressive strength value.

The blocks were tested at pre-prepared moisture contents varying between oven dry (dried at 105° C and cooled) to 2% above the ambient moisture content. In preparation for testing, the tongue and groove elements on the top and bottom bed faces were removed using a handsaw and the blocks were capped with dental plaster. The test results are outlined in Table 14.

---

3 Methods of test for masonry units. Determination of compressive strength.
Table 14 Compressive strength assessment

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Moisture content at compression test</th>
<th>Compressive strength test value (N/mm²)</th>
<th>Average normalised compressive strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>6.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1c</td>
<td>4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2c</td>
<td>4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3c</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4b</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4c</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8.6.3 Flexural strength (MOR)

The flexural strength of the blocks was determined by three-point bending. The blocks were tested at ambient laboratory moisture content (5.7%) following storage at 20°C and 65% RH. The test results are presented in Table 15.

The flexural strength was high and comparable with compressive strength at ambient moisture conditions. Though generally of little practical value, block flexural strength, if particularly low, could limit the bond strength of the masonry and increase the potential for shrinkage cracking on drying.

Table 15 Flexural strength assessment

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Flexural strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
</tr>
<tr>
<td>5</td>
<td>2.3</td>
</tr>
<tr>
<td>6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

8.6.4 Abrasion resistance

The test method was in accordance with that outlined in *Rammed Earth: Design and Construction Guidelines*. A test panel was built at the laboratory using a mortar bonding.

The test used a standard wire brush with a mass of 3 kg fixed to it in order to maintain a constant vertical pressure. Before testing, the panel was dried to constant mass and weighed. The test face was then subject to wire brush abrasion, which consisted of 60 complete backward and forward cycles in 1 minute. No further vertical pressure was applied during the testing. The brushing was directed along the full 300 mm width of the panel and,

throughout brushing, at least half the surface of the brush remained in contact with the test surface. On completion of brushing, any remaining loose material was removed and the panel was reweighed.

The abrasion resistance of the test panel is reported as the area of the brushed surface divided by the mass reduction caused by brushing (cm$^2$/g). The test result with the gypsum–clay block was 42.0 cm$^2$/g. This suggests the block surface has a good resistance to normal surface abrasion. In comparison, the result for an unfired clay brick (Errol Eco-brick, which does not dust on light rubbing) has an abrasion resistance of 18.0 cm$^2$/g.

### 8.6.5 Accelerated spray erosion test

The test method was in accordance with that outlined in *Rammed Earth: Design and Construction Guidelines*. A test panel built at the laboratory using a mortar bonding was subject to a high-pressure water spray for two hours. Performance was measured in terms of maximum depth of pitting.

The minimum recommended test resistance is 60 mm/hour. The test result was 15 mm/hour, which may be considered a satisfactory performance.

The test is useful for comparative performance but cannot be used for predictive indication of likely durability performance, as actual performance depends on many inter-linked factors.

### 8.6.6 Block masonry properties

#### Mortar properties

The mortar based on clay, silica sand and sodium silicate developed for use with the gypsum–clay blocks (see section 7) was selected for testing as this material had proved to be a practical mortar during the other demonstration trials.

Specimens for flexural and compressive testing were prepared in accordance with BS EN 1015-11: 1999, though a thin filter paper liner was inserted before casting to prevent adhesion with the timber moulds (rather than the steel moulds specified in BS EN 1015-11). The mortar specimens were cured for 28 days under ambient conditions of 20°C and 65% RH before testing. The results for flexural and compressive strength are given in Table 16.

The flexural strength of the mortar, in particular, is significantly higher than expected for clay-based or comparable lime based mortars. The mortar performance is very consistent.

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Flexural strength (N/mm$^2$)</th>
<th>Compressive strength (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0</td>
<td>3.2</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>3.1</td>
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<td>3.2</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2.0</strong></td>
<td><strong>3.2</strong></td>
</tr>
</tbody>
</table>

#### Masonry bond strength

Bond strength between blocks joined together with a 2–3 mm thick mortar joint was determined in accordance with BS EN 1052-5: 2005.

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5. *Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar*

Bond tests were undertaken at 3, 7, 28 and 90 days after construction. Specimens were stored in ambient conditions of 20°C and 65% RH. The results are summarised in Table 17.

Very high bond strength values were achieved using the mortar (especially for unfired clay block masonry). Full bond strength was achieved at three days (possibly sooner), with no further significant and consistent strength gain with time. The reduction in strength at 90 days was not considered significant as the specimens prepared for this test were those prepared first and the lower strength was attributed partially to the inexperience of the operator in handling the blocks and using the mortar/jointing system.

### Table 17 Bond test values

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>3 days</th>
<th>7 days</th>
<th>28 days</th>
<th>90 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.81</td>
<td>0.90</td>
<td>0.83</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
<td>0.87</td>
<td>0.95</td>
<td>0.70</td>
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<tr>
<td>3</td>
<td>0.76</td>
<td>0.83</td>
<td>0.91</td>
<td>0.50</td>
</tr>
<tr>
<td>4</td>
<td>0.99</td>
<td>1.06</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>5</td>
<td>0.85</td>
<td>0.91</td>
<td>0.88</td>
<td>0.73</td>
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<td>6</td>
<td>0.79</td>
<td>0.91</td>
<td>0.78</td>
<td>0.66</td>
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<tr>
<td>Average</td>
<td>0.84</td>
<td>0.91</td>
<td>0.83</td>
<td>0.65</td>
</tr>
</tbody>
</table>

### 9.0 Conclusions

Unfired clay-gypsum blocks have been successfully manufactured using a horizontal extrusion process using processed plasterboard from recycled sources and these products have been successfully demonstrated at a range of sites across the UK. A 50% addition of recycled plasterboard was used for the production trials, though this content could be optimised further.

A number of demonstration walls were successfully constructed during the project using the gypsum–clay blocks. These walls are available for future reference.

The gypsum–clay product has the potential to incorporate plasterboard from new build sources as well as from construction and demolition (C&D) sites where contamination levels are potentially higher. Minimal pre-processing of the plasterboard is required as the fibre content of the backing paper has the potential to improve the flexural strength and ‘fixing’ properties of the block.

Unlike traditional fired clay construction units, the block products were not fired but are air or force dried. Their production therefore has fewer associated carbon dioxide emissions and the blocks have a low embodied energy. They contain little or no cement (unlike cement-bonded aggregate blocks) and do not require recalcination of the gypsum to facilitate its recycling before it is incorporated into the block. The product has enhanced physical properties compared with natural clay.

During the project, a number of other production process techniques were investigated including vertical extrusion and pressing. The Oskam pressing process was examined as pressing is traditionally used to manufacture concrete blocks. However, pressing a fine plasterboard-clay mix would be problematic due to lamination issues associated with de-airing such a mix during compaction. Extrusion was felt to be a more suitable process as the technology is already available at brickworks and would enable the use of a processed plasterboard. Horizontal extrusion is generally used to produce large volume standard bricks whereas vertical extrusion is limited to the production of a smaller number of more detailed products.

A number of mortar systems were investigated and a sodium silicate based mortar was found to give an excellent bond with the unfired gypsum–clay blocks.

A number of plaster systems were also assessed and a number of material options are available which complement the blocks.
Products containing 50% recycled plasterboard are now being supplied on a commercial basis by Back to Earth (www.backtoearth.co.uk); 100 mm blocks are being offered as these compare well with traditional concrete blocks and are easier to handle than 120 mm blocks.

The gypsum–clay block product will now be marketed and distributed to develop the market further. Further trials are planned to optimise the use of higher additions of recycled plasterboard within the block matrix.

An initial assessment of the market for such a product indicates that there is an immediate market for over one million blocks per year. Assuming a 50% addition, this would create an annual market for over 9,000 tonnes of recycled plasterboard.

9.1 Recommendations
Further product development work to address the water resistance/water proofing of the unfired block is recommended to broaden the market for the product into applications where it can compete against traditional concrete blocks.

Further development work to improve the compressive strength of the product may enable the use of the product in more demanding structural environments.