



Characterisation of Mineral Wastes, Resources and Processing technologies – Integrated waste management for the production of construction material

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Industrial sector study on the utilisation of alternative materials in the manufacture of manufactured concrete products

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1. Scope

This report describes the results of an assessment of the role of alternative raw materials derived from mineral wastes in the concrete products manufacturing sector. The report reviews the manufacturing processes and markets for manufactured concrete products, examines the current sustainability issues in the sector, and assesses the current use and potential utilisation of alternative raw materials derived from mineral sources. It also describes the key properties for these materials for use in concrete products, reviews current waste exchange mechanisms in the sector and recommends materials characterisation frameworks, relevant standards and quality protocols to encourage the wider utilisation of mineral wastes.

The report focuses on manufactured (pre-cast) products. Ready-mixed concrete (for placement on construction sites), site batched concrete and mortars are beyond the scope of this study.

The use of recycled and secondary materials as aggregates in concrete (see Box 1) is well served by WRAP's AggRegain website[1]. Wherever possible, this report focuses on the use of mineral wastes in the products generally although it is impossible to avoid aggregate applications and as such, there is inevitably some overlap with WRAP.

This report covers dense concrete products and aerated concrete. The two product groups are distinctly different in their manufacture and are therefore discussed separately.

Box 1: Aggregates in concrete
Primary aggregates Granular material used in construction produced from natural materials.
Secondary aggregates Aggregates produced from by-products of other industrial processes and not previously used in construction [1]
Recycled aggregates aggregates derived from reprocessing materials previously used in construction [1]

2. The manufactured concrete product sector in the UK

Broadly speaking, concrete products contain the following ingredients:

- a) Aggregates (granular material- aggregates can be primary, recycled or secondary)
- b) Binders
 - o materials such as Portland cement or lime which react chemically)
 - o Pozzolanas (materials such as pulverised fuel ash (pfa)- also known as fly ash- which react chemically and harden in combination with lime and/or Portland cement)
- c) Water
- d) Minor additions (pigments, admixtures, workability aids etc)

Aggregates, binders and pozzolanic materials are covered by a range of product standards and quality protocols.

The key examples are:

- o BS EN197-1: 2000 Cement: part 1: composition, specifications and conformity criteria for common cements [2]
- o BS 3892-1:1997 Pulverized-fuel ash. Specification for pulverized-fuel ash for use with Portland cement [3]

- BS 3892-2:1996 Pulverized-fuel ash. Specification for pulverized-fuel ash to be used as a Type I addition [4]
- BS EN 450-1:2005 Fly ash for concrete. Definition, specifications and conformity criteria [5]
- Waste Protocols Project. Blast Furnace Slag (BFS): a technical report on the manufacturing of blast furnace slag and material status in the UK [6]
- British Standard Specification for Air-cooled blastfurnace slag aggregate for use in construction. BS 1047; 1983 [7].
- WRAP, Quality Protocols for the productions of recycled aggregates from inert waste in England, Scotland and Northern Ireland, 2004 and 2005, WRAP, Banbury. Available online at www.aggregain.org.uk/quality [8]
- BS EN12620: 2002, aggregates for concrete [9]

Portland cement manufacture accepts a range of alternative materials and fuels derived from mineral waste. These are covered separately in the Sector Study Document for the manufacture of common cements [10].

There are numerous CEN product standards for pre-cast concrete products. The main examples that cover the more commonly used products include:

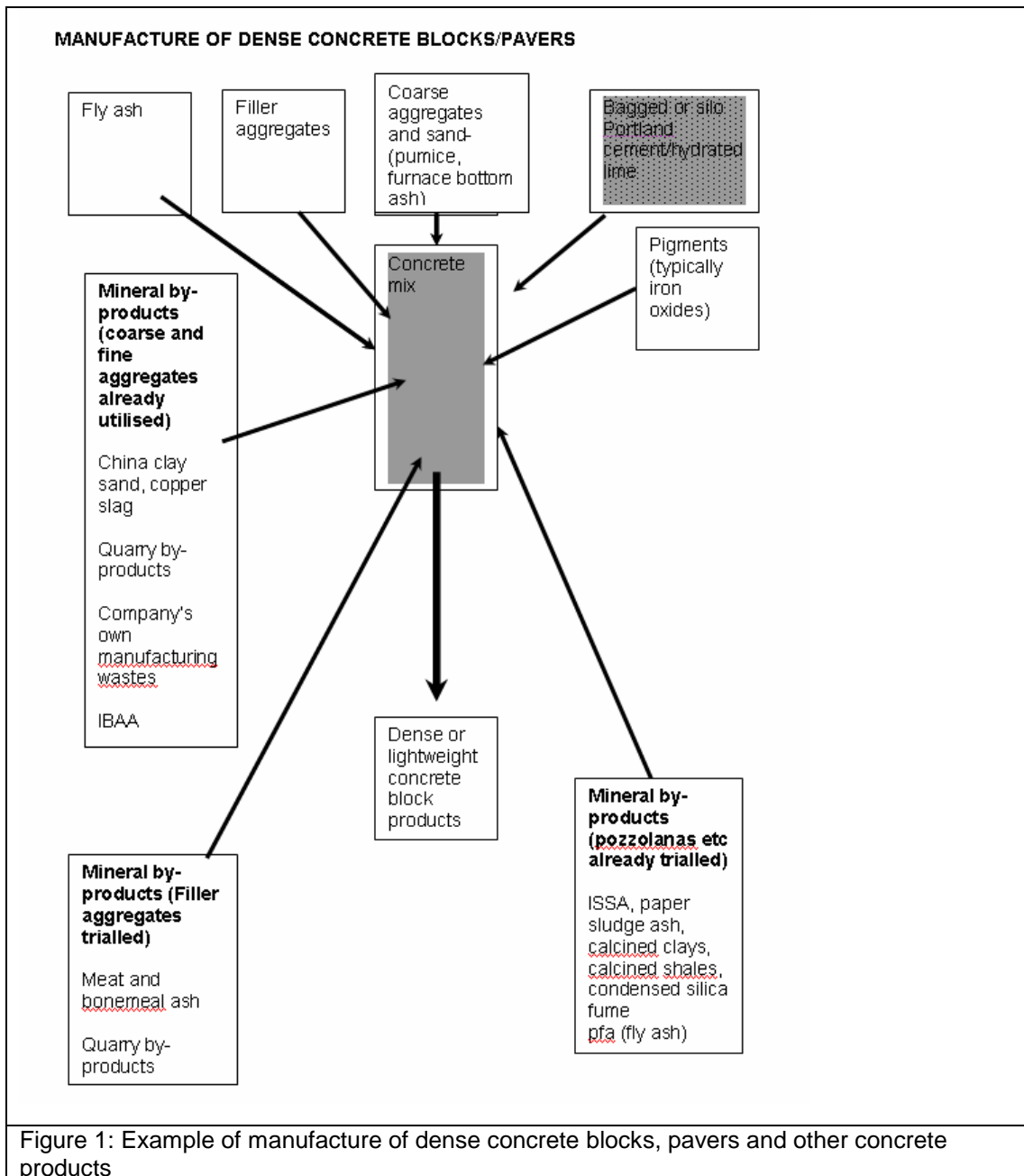
- BS EN 1338:2003 Concrete Paving Blocks: Requirements and test methods[11].
- BS EN 771-3: 2003 Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates)[12]
- BS EN 490: 2004 Concrete roofing tiles and fittings for roof covering and wall cladding. Product specifications[13]
- BS EN 771-4: 2003 Specification for masonry units. Autoclaved aerated concrete masonry units[14]
- BS EN 1916: 2002 Concrete pipes and fittings, un-reinforced, steel fibre and reinforced[15]
- BS EN 1168: 2005 Precast concrete products. Hollow core slabs[16]

2.1 Manufacturing Process overview: dense pre-cast products

- 1) Pre-cast concrete elements and components such as kerbs, floor units, stair-cases pipes and reconstituted stone products are manufactured using a variety of fabrication methods. Some are manufactured using wet-casting processes in a similar manner to ready-mixed concrete. Others are pressed or extruded using semi-dry processes. These products may contain reinforcing steel or may be un-reinforced.
- 2) Aggregate concrete blocks are made from cement, sand and aggregates and are classed as either dense or lightweight. In both cases, the mix is moulded and then cured in heated chambers (curing temperatures range from approximately 30°C to 50°C). Lightweight blocks differ in the weight and nature of the aggregate component. Conventional lightweight aggregate is pumice or is thermally manufactured by expanding shale and clay in a rotary kiln (see the Industrial sector review on *Manufactured Aggregates*). Furnace bottom ash (FBA- from coal-burning power stations) or air-cooled blastfurnace slag (from steel manufacturing) are also used. These obviate the need to produce artificial lightweight aggregates thus dramatically reducing the embodied energy.

Autoclaved aerated concrete (AAC) blocks are used in the same kinds of applications as some kinds of aggregate concrete blocks (such as the inner leaf of cavity walls for example). The manufacturing equipment and processes for manufacturing AAC products are very different from those involved in aggregate block production and other pre-cast products such as kerbs, floor units etc.

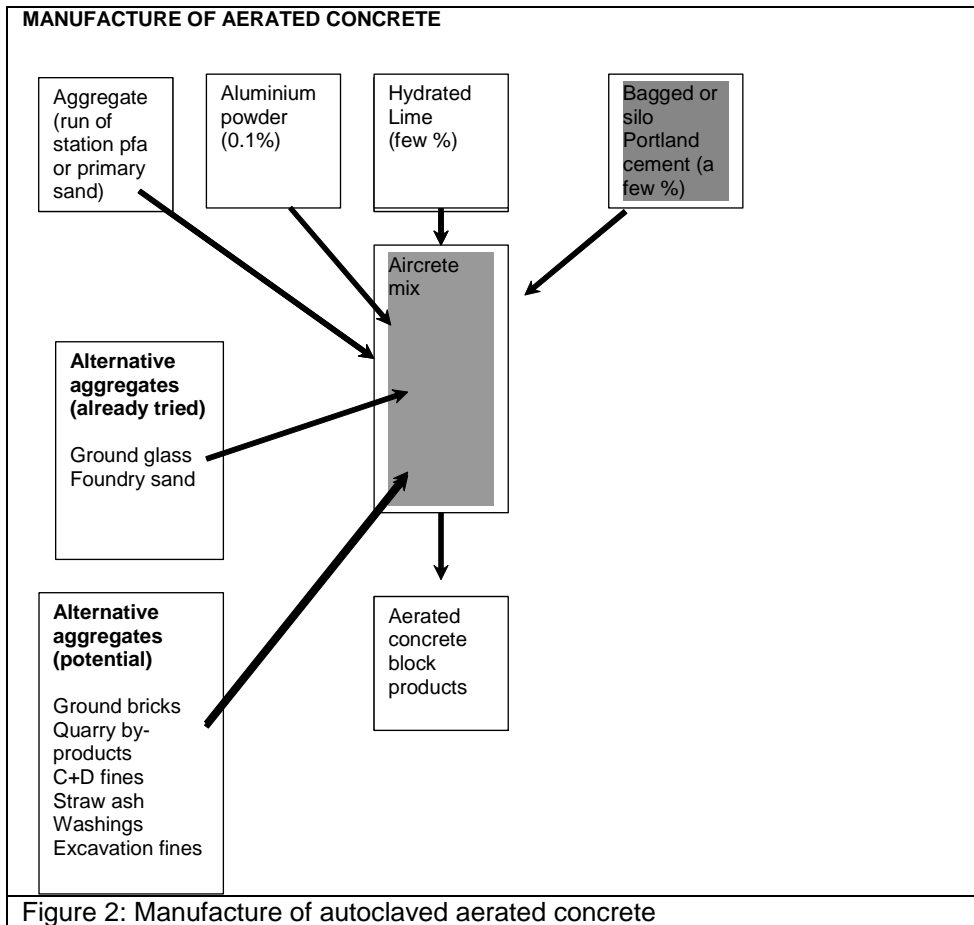
The generic ingredients for the manufacture of dense concrete products are illustrated schematically in Figure 1 below. The ingredients comprise reactive components (such as cement, lime, water, pfa) and aggregates which are essentially inert.



2.2 Process overview: aerated concrete products

Autoclaved aerated concrete (AAC) is a factory produced product which is cured under elevated temperatures and pressures in an autoclave process during which the main ingredients (including the finely divided aggregates) react together chemically. Aerated concrete comprises cement, lime, fine aggregates, with a few per-cent of aluminium powder added to the mix to aerate the product. The aggregate comprises the major constituent of the mix. The aerated concrete industry has a history of utilising by-product materials as aggregate, the most common of which is pfa. The wet mixture is cast into large "cakes" (each several cubic metres in size), which are left to "rise" and set. The soft cakes are subsequently

sawn into blocks and then autoclaved to achieve a high degree of cementitious reactions between the aggregate, cement and lime.



2.3 Products and markets

Pre-cast concrete products, particularly block products, generally have a history of accepting blends of traditional and by-product materials into their manufacture. The different types of pre-cast concrete products produced by the members of the main trade association (the British Pre-cast Concrete Federation) for use in building construction include:

- Retaining, Revetment & Crib Walls
- Pipes & Drainage
- Box Culverts
- Manholes & Inspection Chambers
- Water Treatment & Storage Tanks
- Kerbs & Flags
- Paving (Block and Decorative)
- Concrete Bricks
- Cast Stone Architectural Units
- Lintels, Sills & Copings
- Foundation Units & Piles
- Hollow core & Composite floors
- Staircases & Stair Units
- Roof Tiles
- Cladding & Structural Wall Units
- Frames, Beams & Columns
- Fencing
- Ducts, Conduits & Markers
- Walling/masonry Blocks

The largest market share of the pre-cast concrete industry is taken up by (in order):

1. Masonry/concrete blocks
2. Paving slabs and paving blocks
3. Roof tiles
4. Pipes and associated products
5. Floor units

2.3.1 Masonry/concrete blocks

Blocks can be sub-divided into:

- Aggregate concrete building blocks (including solid blocks and blocks with formed voids- (BS EN 771-3 Aggregate Concrete Masonry Units)[12], (see Figure 3).
- AAC blocks

Autoclaved aerated concrete (AAC) blocks are commonly known as “aircrete” blocks. The other types of concrete block used in construction are aggregate concrete blocks, either dense or lightweight. Of the 90 million m² production of concrete blocks in 2005, AAC blocks accounted for one-third (28 million m²), dense aggregate blocks for 40 per cent (36 million m²), and lightweight aggregate blocks for 28 per cent (25 million m²)[17].



Figure 3: Typical dense aggregate concrete building blocks in the factory (Stowell Concrete)

2.3.2 Tiles, paving slabs and paving blocks

National statistics [18] indicate that UK manufacturer sales of concrete tiles, flagstones and similar articles were approximately 10.8 million tonnes in 2006. Detailed statistics on block pavers are difficult to find. However, estimates indicate that the market for block pavers in the UK is approximately 23 million sq metres per annum.

2.3.3 Pipes and associated products

National statistics [18] indicate that UK manufacturer sales of these components (including walls, panels, foundations, tunnel sections) were approximately 980,000 tonnes in 2006.

2.3.4 Prefabricated structural components

National statistics [18] indicate that UK manufacturer sales of these components (including walls, panels, foundations, floors, tunnel sections) were approximately 5.3 million tonnes in 2006.

2.4 Sustainability issues and the manufacture of concrete products

The cement industry is heavily focused on sustainability and the timber and steel construction sectors already have their own sustainability strategies. The pre-cast concrete sector is currently developing its strategy [19]. The concrete sector body (the Concrete Centre), is also concerned with improving the sustainability of the sector and give details on their website.

Building elements for the construction of upper floors, external walls and load-bearing partitions based on dense concrete blockwork or AAC are among the best performers, scoring a summary rating of "A" in the Green Guide to Specification^{*}. However, the Green Guide is regularly updated and the ratings become more difficult to achieve as industries' environmental performance improves. This provides a strong driver for the concrete industries to maintain and improve their environmental performance.

Pre-cast concrete product manufacture generates very little manufacturing waste (a few per cent), as materials and rejects from the production can be fed back into the manufacturing process. Manufacturers of concrete roof tiles, paving blocks and floor beams/units are already known to recycled their own production waste in this way. There is some generation of installation waste on site and manufacturers are expected to introduce take-back schemes for site-generated waste over the next 1-2 years with the introduction of compulsory site waste management plans.

Portland cement production is associated with CO₂ emissions 0.83 tonnes produced per tonne of cement. (source, the Concrete Centre). Concrete products, however, typically have a long life (50 years or more), which increases their sustainability performance.

Sustainability drivers that are impacting on the sustainability initiatives of the manufactured concrete products sector include:

- The Code for Sustainable Homes is a legislative requirement which sets requirements for all elements of house construction.
- Compulsory site waste management plans (SWMP) for construction sites.
- Government targets that require low-impact buildings; including reducing carbon emissions by 60% by 2050.

^{*} The Green Guide to specification gives an assessment of construction materials and elements based on their environmental impact over their life cycle. "A" is currently the highest rating. Indicators include greenhouse gas emissions, minerals extraction and waste generated.

- WRAP's campaign to promote recycled content in construction products (benchmark is currently a minimum of 10% recycled content by value).
- Major procurement activities (such as for the Olympics 2012) are increasingly demanding recycled content. The Olympics materials procurement policy demands the use of products with recycled content.

3. Alternative raw material usage in the concrete product manufacturing sector

This section describes examples and criteria for the use of alternative raw materials. It covers manufactured concrete products, excluding AAC products.

Industrial by-products such as pfa and ground granulated blastfurnace slag (ggbs) and other ashes have a long history of acceptance in manufactured concrete products. Other mineral by-products or wastes (such as various bottom ashes, clinkers or slags), have also found a high degree of acceptance. However, the greatest potential for the introduction of new or more unfamiliar materials is into aggregate concrete blocks which have a long history of acceptance of such materials. There is also potential for the use of alternative raw materials in products for non-critical applications where some combination of characteristics including: low strength, non-structural use, easy access for replacement is possible or if visual appearance is not critical. Examples of such products where there is most potential, these have been underlined in the list above. The main sectors of the industry that are currently accepting or actively seeking new alternative materials (other than the usual pfa, ggbs or their own production waste) are as follows:

- a) Manufacturers of hard landscaping products (eg block paving, paving slabs)
- b) Concrete block/masonry manufacturers
- c) Concrete roof tile manufacturers

The manufacturers of products such as concrete blocks, fence posts, cable trunking etc are engaged in extremely competitive commodity markets with high volumes and low profit margins. The main drive for manufacturers attempting to source alternative raw materials is simply to reduce their manufacturing costs, but still having absolute confidence in performance/durability of the finished product.

For producers of landscaping products, (such as block pavers), there is more scope to create demand for alternative materials by introducing specific "environmentally-friendly" product ranges (for example, Marshalls "Eco" range). These are "added value" products and there is more scope to increase production cost and improve sustainability for greater consumer appeal.

Cast stone architectural units are special manufactured concrete products such as coping stones and balustrades, designed to mimic natural stone. With these products, appearance and maintenance of appearance over time are key. Manufacturers simply will not risk the use of alternative raw materials where there is any perception of risk and rely on stone powders from very reliable and consistent sources.

3.1 Key requirements

The key requirement for mineral raw materials for manufacturers of concrete products can be summarised as follows:

- a) Aggregates (meeting the requirements of the WRAP quality protocol for aggregates from inert waste and without the presence of deleterious materials such as free lime, unburnt coal etc)
- b) Binder (materials such as Portland cement or lime which react chemically)
- c) Pozzolanas (pfa or ggbs meeting the requirements of relevant standards. Concrete blocks can accept lower specification materials such as “run of station”, stockpiled or lagooned/conditioned pfa)

Manufactured concrete products lend themselves well to the incorporation of mineral by-products because the manufactured products are required to meet particular end product specifications, standards, or regulations irrespective of the ingredients[†]. Nevertheless, certain properties are essential to the manufacturer. As a useful starting point, alternative feedstocks can be judged against the ratified European Standards for aggregates, and those for reactive ingredients with fine particle size, against those for pfa.

Critical properties that the manufacturer expects from raw materials and the end product (concrete product) properties is set out below (Table 1).

Table 1: Feedstock and end product properties for mineral wastes in manufactured concrete products

Product group	Feedstock properties	Handling properties (manufacture/process related)	End product properties
Manufactured concrete products	<p><u>As aggregate or fine filler:</u> Grading, chloride content, sulfate content, effects on setting of cement, strength, ASR reactivity, water demand</p> <p><u>As cement replacement (or pozzolana):</u> Fineness, strength activity, effects on setting of cement</p> <p><u>Cement/binder:</u> Meeting the physical and chemical requirements of BS EN 197-1</p>	Particle size, moisture content, ease of flow (powder), Mixing compatibility with other constituents	Issues such as strength properties, drying shrinkage within defined limits, frost resistance. There are product standards for products such as kerbs, block pavements, concrete blocks etc

[†] This is not the case with ready-mixed concrete

3.2 Substitute materials

Examples of the current situation with the use of mineral by-products in the manufactured concrete product industry are given in Tables 2 below. The new uses identified to BRE are all alternative sources of recycled and secondary aggregates. Filler aggregates in blocks such as pfa and coarse aggregates such as furnace bottom ash (FBA) are well established and accepted throughout the industry. Indeed, FBA is at present in demand and imported into the UK. One of the concrete block manufacturers (Plasmor®), manufactures their own lightweight aggregates from expanded clay.

A major project supported by WRAP known as Conglasscrete[20] conducted industrial trials with concrete products containing post-industrial crushed glass as aggregate and ground glass as pozzolana. Products were successfully manufactured and their properties were found to meet the requirements of the relevant CEN product standards. Examples of dense aggregate concrete blocks from the project, manufactured by Stowell Concrete, are shown in Figure 3.

The Green Guide to specification and BREEAM, both of which provide an assessment of environmental impact of buildings or components, take into account (positively) the use of recycled materials instead of primary materials. The use of alternative raw materials impacts positively in this regard.

Table 2a: List of alternative materials/wastes with the potential to be used in manufactured concrete products (dense and lightweight aggregate blocks) and the progress made so far by the industry in the UK

No.	Recycled material	Progress	Ingredient	Comment
1	Incinerated sewage sludge ash	Unsuccessful trial	Aggregate	Consistent production difficult due to variable water demand.
2	IBAA	Formerly used in production until end product problems	Aggregate	Abandoned use due to pop-outs. Processing at the time could not guarantee absence of non-ferrous metals
3	Glass	Trials [20]	Aggregate	Concern about product durability
4	Quarry waste	Used in production	Aggregate	

Table 2b: List of alternative materials/wastes with the potential to be used in manufactured concrete product (paving slabs, blocks, tiles) and the progress made so far by the industry in the UK

No.	Recycled material	Progress	Ingredient	Comment
5	Crushed concrete from concrete production	routinely used in production (Paving slabs Paving blocks)	Aggregate	Seen by companies as environmentally and cost acceptable way for dealing with own production waste. Effects of water absorption of material on the mix water demand limits percentage added.
6	Crushed stone from natural stone manufacturing	routinely used in production (Paving slabs Paving blocks)	Aggregate	Seen by companies as environmentally and cost acceptable way for dealing with own production waste. Effects of water absorption of material on the mix water demand limits percentage added.
7	Copper slag decorative surface	routinely used in production (pre-cast concrete flag kerb and edging)	Aggregate	Used for decorative properties in a range that is specifically marketed for its "eco" credentials
8	Slate waste	routinely used in production (artificial slates)	Aggregate	-
9	China clay waste (Stent)	routinely used in production (granite-effect paving)	Aggregate	-

There is interest in the construction industry currently in the use of low carbon (alternative) cements. These cements, which may have a high content of industrial by-products, are mentioned in reference [10, 20]. The use of ggbs or pfa as a partial replacement for Portland cement in concrete products is widely practiced and accepted.

Table 3 presents the industry's current response regarding the utilisation of alternative materials plus the potential benefits/barriers, as well as the types of analysis required during the waste exchange process.

Table 3: Classification of industry's responses regarding the utilisation of alternative materials/ waste in manufactured concrete products. (Key: Recycled material; Categories of benefits/ barriers: MR=material related, EC=economic, ENV=environmental, SO=social; Barriers are also classified according to their significance (similar to WPP database) → 1=significant, 2=important, 3=less important, 4=future work will define significance)

Recycled material	Potential benefits	Potential barriers	Analytical techniques
1 (ISSA)	Raw material cost savings (Filler) EC = 1 Reduce environmental impact ENV = 3	MR=1 (mixing variability) SO= 2 (public perception)	Chemical analysis Workability (concrete) Compression strength (concrete) Durability (concrete) would also be required.
2 (IBAA)	Raw material cost savings EC = 1 Alternative aggregate Reduce environmental impact ENV = 3 Large tonnages, widely available (potentially)	MR = 1 (pop-outs) SO = 2 (perception-dioxins in Incinerator fly ash)	Free non-ferrous metals content
3 (glass)	Raw material cost savings EC = 2 Alternative aggregate Reduce environmental impact ENV = 2	MR = 4 (Concern about durability)	Chemical analysis Bulk density Particle size analysis
4 (quarry waste)	Large tonnages, widely available (potentially)	None	Chemical analysis (required) Bulk density (required) Particle size analysis (required) Water absorption (required)
5 (crushed concrete)	Saving on waste transport costs EC = 1 Avoid landfill charges EC = 2 Environmentally acceptable way for dealing with production waste ENV = 2	MR= 3 (water demand)	Water absorption
6 (crushed stone)	Saving on waste transport costs EC = 2 Avoid landfill charges, ENV 2 Environmentally acceptable way for dealing with production waste ENV= 2	MR= 3 (water demand)	Water absorption
7 (copper slag)	Decorative effect	None	None
8 (slate waste)	Appearance	None	Not known
9 (Stent)	Appearance	None	Not known

3.3 Characterisation Framework

A characterisation framework for alternative raw materials for manufactured concrete products will typically include the following:

Table 4: Characterisation framework for alternative raw materials for manufacture of concrete products (excluding AAC)

General requirements	
Physical condition/appearance	Moisture content
Mineralogy	Particle size range
Oxide composition	Loss on ignition

Manufactured concrete products
<ul style="list-style-type: none">• Mineralogy• Chemical analysis• Colour• Particle size analysis• Water absorption• Moisture content• Sulphate• chloride• Materials that may affect setting• Bulk density
Followed by:
<ul style="list-style-type: none">• Workability (concrete)• Durability (concrete)• Compression strength (concrete)

3.4 Standards and protocols

There are a variety of product standards for manufactured concrete products which are mentioned earlier. The European standards for aggregates are performance based and do not unnecessarily exclude or disadvantage recycled or secondary materials.

WRAP and the Environment Agency have recently agreed that blast furnace slag is a by-product and will not have a quality protocol for blastfurnace slag. This re-classification of blast furnace slag gives clarity over the materials standing within waste regulations and bringing clarity to its use [see 6].

4. Guidance on assessing alternative raw materials for the concrete products manufacturing sector

4.1 Waste exchange

Many concrete blocks and hard landscaping products already include well known by-products and recycled/secondary aggregates including recycled concrete aggregates (RCA- from crushed production waste), furnace bottom ash (FBA), pfa, ggbs, china clay sand, china clay stent. These are all well known and their use is extensively covered by bodies such as WRAP that provide tools and information to encourage and facilitate their use[1].

The form of waste exchange involving alternative feedstocks to these depends on the nature of the manufacturing business. Vertically integrated businesses utilise wastes and by-products from their group operations (such as stone waste, water treatment wastes or production waste) into their products. Manufacturers that are less vertically integrated, typically source mineral by-products through contacts with independent waste management companies or waste brokers. Some materials companies undertake to provide the manufacturers with materials that meet quality, quantity and availability requirements.

Manufacturers will typically be presented (by the broker or waste holder) with an oxide chemical analysis and particle grading for a by-product. If this looks favourable, the manufacture may typically proceed with laboratory trials (preceded by further materials tests if necessary), with eventual scale-up to pilot-scale trials. All this is subject to the usual non-technical considerations such as availability, location and price. There are instances where, once a demand has been established, the price of by-products can increase so that it is no longer commercially viable. Manufacturers should try to agree a price for the material in advance of the trial, provided certain criteria are met or exceeded in the trial.

Quality schemes (such as the WRAP quality protocol for aggregates from inert waste)[8] have assisted with the acceptance of recycled aggregates as a product rather than a waste. Further protocols are in development for pfa, incinerator bottom ash aggregates and aggregates produced from contaminated soils. Quality schemes for other generic ingredients suitable for use in concrete products may assist their uptake by redefining them as co-product rather than waste.

The behaviour of the industry regarding the use of alternative materials can be summarised in the following:

- Alternative aggregates actively are sought where there is a cost saving and/or it assists the company's environmental policy
- In landscaping products and tiles, there can be clear aesthetic benefits in alternative materials and more of a customer interest in eco-products, particularly in the home-improvement market.

The barriers to the use of alternative by-products forward are:

- Location of raw materials relative to production plant may make waste exchange uneconomic
- Cost and consistent supply guarantees
- Limited information on alternative materials to those used currently

The drivers seen that could move the use of alternative by-products forward are:

- Landfill tax escalator
- Customer product demand
- Collection systems for mineral by-products
- Shareholder demands and corporate social responsibility policies
- Aggregates levy (currently £1.60 per tonne payable on primary aggregates)
- Reduction in coal burning power station capacity in the UK (reducing the supply of pfa and furnace bottom ash)

Criteria for manufacturers to develop partnerships with raw material suppliers are likely to include:

- Guaranteed quantities and sizes of deliveries
- Content and quality of deliveries
- Agreement to a fee or co-financing of waste handling costs (including chemical analysis, test runs, approvals, any additional environmental or safety measures).

4.2 Future developments

Future developments in the sector are expected to include the greater use of alternative ashes and aggregates as further quality protocols are introduced. Recycling of waste from construction and refurbishment is likely to increase with the introduction of more take-back schemes. The Landfill tax escalator is also expected to drive the use of new alternative raw materials. The drive for sustainable procurement (promoted by WRAP and others) is also a strong source of influence on producers of concrete products.

5 Alternative raw material usage in the AAC manufacturing sector

This section of the report describes examples and criteria for the use of alternative raw materials. It specifically covers AAC products.

The AAC industry in the UK is dominated by the following companies:

- H + H Celcon Ltd
- Tarmac Topblock Ltd
- Hanson Building Materials Ltd
- Quinn Group (Northern Ireland)

Pfa has a long history of acceptance in manufactured concrete products. Manufacturers can also incorporate a limited quantity of their own production waste into the product. The limit is about 10% by weight of total aggregate due to a loss of block compressive strength associated by increased water demand in the process.

The AAC manufacturers are keen to achieve access to a wider source of aggregate raw materials, principally to minimise costs associated with transport of these raw materials (eg pfa) from power stations and/or natural sand quarries- which also attract the aggregates levy. Manufacturers consider it unnecessary to risk using sources of by-product lime or aluminium which offer limited gains as they are relatively minor components in the mix.

The majority of AAC factories are either within a moderate distance from major coal burning power stations or have their own source of natural sand nearby, so alternative sources of

material have not been considered necessary. There are examples of plants where a local source is not available and alternative aggregate or by-product sources are therefore actively being sought.

Data have been collected after discussion with the main UK manufacturers. A summary of the results are presented in Table 5 and Table 6. However, in all cases, materials-related barriers (generally related to handling) have caused work not to proceed beyond the works trials stage.

Table 5: List of alternative materials/wastes with the potential to be used in aerated concrete and the progress made so far by the industry in the UK

No.	Recycled material	Progress	Comment
1	Run-of-station pfa	In use	Accepted material as aggregate
2	Waste glass cullet	Works trials	Possible alternative aggregate source that has been considered over the last 15 years. Not currently being pursued due to handling problems (insufficient fineness for grinding). Cost > primary aggregates, supply quantity variable
3	Foundry sand	Works trials	Possible alternative aggregate source. Abandoned due to handling problems (dark colour, odour in process, health and safety concerns)

5.1 Key requirements

The key requirements for alternative raw materials for AAC are for aggregates. In AAC, the aggregates have a small particle size and participate in the setting and hardening reactions. The most commonly used materials are primary sand and a single quality assured source of pfa. However, various alternatives can be considered as long as they meet the manufacturer's acceptance criteria (Section 5.3).

5.2 Substitute materials

Table 6: Classification of industry's responses regarding the utilisation of alternative materials/waste in AAC. (Key: Recycled material No= look at list of table 1; Categories of benefits/ barriers: MR=material related, EC=economic, ENV=environmental, ORG=organisational, SO=social; Barriers are also classified according to their significance (similar to WPP database) → 1=significant, 2=important, 3=less important, 4=future work will define significance)

Recycled material No.	Material	Potential benefits	Potential barriers	Analytical techniques
1	Run-of-station pfa	Widely available	EC = 2 (transport)	Chemical analysis
2	Waste glass cullet	Flexibility in sourcing aggregate	MR = 1 (insufficient fineness)	Chemical analysis
3	Foundry sand	Flexibility in sourcing aggregate	MR= 1 (odour)	Chemical analysis

5.3 Characterisation Framework

From discussion with AAC manufacturers, it was found that different alternative materials may in principle play certain generic roles within the manufacture of aerated concrete products (Figure 1). However, the efforts of the industry are almost entirely focussed on:

- Fine Aggregates/filler aggregates (natural sand)
- Pfa

Both the above generic material types react chemically in the aerated concrete manufacturing process. Cements, lime and aluminium powder are all minor ingredients (in terms of quantity), where alternative materials offer limited benefits in relation to the perceived risk. In contrast to bricks, colour is not critical, although very dark coloured materials (such as certain foundry sands) may not be acceptable.

Alternative materials that match the above categories are shown in Figure 2. The operational envelope for their sources of pozzolanas (from an AAC manufacturer) is shown in Table 7.

Table 7: Operational envelope for run-of-station (fresh hopper) pfa intended for AAC production

Pfa property	Desirable %	Usable %	Undesirable/Unusable %
SiO ₂ content	>55	45-55	<45
Al ₂ O ₃ content	15-20	20-30	>30
CaO content	<5	5-10	>10
MgO content	<1	1-2	>2
SO ₄ ²⁻ content	0.5-0.55	0.55-0.65	>2.5
45 micron residue	12.5-15	15-30	>30
Loss on ignition	3-6	6-8.5	>8.5
Delivered moisture content of conditioned pfa	10-12	12-15	>15

NOTES for the above table

- ii. High levels of SiO₂ are desirable to react with the binders for strength development. There appears a general inverse strength relationship between the SiO₂ and Al₂O₃ levels in pfa i.e. increasing the Al₂O₃ level at the expense of SiO₂ reduces AAC strength.
- iii. Pfa's with high CaO content can undergo undesirable expansion under autoclaving conditions. They can also result in an imbalance in the CaO:SiO₂ ratio of the mix recipe, causing a reduction in AAC strength, and undesirably thicken production slurries which in turn increases water demand and can also result in loss of strength.
- iv. High levels of MgO are deemed to cause expansion under autoclaving conditions, potentially resulting in catastrophic loss of strength.
- v. Unduly high levels of SO₄²⁻ can cause thickening of process slurries with the potential adverse effect on strength described above.
- vi. If a pfa has a low 45 micron residue, and the fine material is present as spherical particles (cenospheres) which can undergo reaction with the binders, then this is advantageous. Conversely if the fine material is not reactive cenospheres then a coarser pfa can be advantageous in the process by reducing slurry water demand.
- vii. Pfa's with high loss on ignition/carbon content can undesirably increase water demand in the process.

viii. It is desirable to use low levels of water to condition the pfa the minimum level being governed by environmental considerations e.g. the desire to prevent dust spillage from lorries during delivery. High water contents are undesirable commercially, can cause lumps to develop within the pfa during transit which are difficult to disperse in making production slurries, and can cause sticking to the lorry and increase discharge times.

A characterisation framework for alternative raw materials for AAC will typically include the following:

Table 8: Characterisation framework for alternative raw materials for manufacture of AAC

General requirements	
Physical condition/appearance	Moisture content
Mineralogy	Particle size range
Oxide composition	Loss on ignition

Aerated concrete
<ul style="list-style-type: none"> • For Pfa: • SiO₂ content • Al₂O₃ content • CaO content • MgO content • SO₄²⁻ content • 45 micron residue • Loss on ignition • Delivered moisture content (if conditioned pfa) • For by-products other than pfa: • Mineralogy • Chemical analysis • Colour • Bulk density • Particle size analysis • Water absorption • Moisture content • Sulphate • Workability (mix) • Compression strength (concrete)

5.4 Standards and protocols

There are British and European standards for pfa (which is the main industrial by-product currently used in the production of AAC). "Run of station" ash (not meeting the requirements of these standards), may also be suitable. The acceptance procedures given above are likely to be adequate for initial screening of ash sources or any other alternative ashes or materials being considered as a substitute for sand or pfa in AAC.

A draft Quality Protocol for the use of pfa is currently being finalised and should be published by the end of 2007.

6 Guidance on assessing alternative raw materials for the AAC manufacturing sector

6.1 Waste exchange

As a result of their own environmental policies, companies are now actively seeking alternative raw materials. However, individual aggregate companies, waste holders or their intermediaries will typically approach the AAC producers directly with details of possible alternative aggregate materials.

Most of the industry sources its mainstream aggregate ash materials from the pfa supply industry which is well established. With unprocessed “run-of-station” ash (which is quite suitable), the material is typically supplied “free” with the manufacturer covering the cost of transport. Suppliers typically undertake to supply the manufacturer with run-of-station ash material within a certain envelope of chemical composition, moisture content and particle fineness.

Technical managers in the main AAC manufacturing companies with works that do not have a local source of primary sand or pfa are actively seeking alternative raw materials through networking with waste producers or intermediaries. Assessment involves a step-by-step approach. Initial screening takes place by comparing the material against the raw materials envelope. Commonly, the user is provided with some samples of material plus any information on its chemical composition. Once any gaps in the materials information have been filled, this is followed by pilot scale trials with promising materials.

The behaviour of the AAC industry regarding the use of alternative materials can be summarised in the following:

- Alternative aggregates are only sought where there is not a local source of pfa or sand
- There is no driver to use alternatives to pfa under other circumstances

The barriers to the use of alternative by-products forward are:

- Cost and reliable supply of materials such as ground glass of sufficient fineness
- Limited information on other alternative materials
- Readily available, local and large supplies of primary sand and/or pfa

The drivers seen that could move the use of alternative by-products forward are:

- Aggregates levy
- Reduction in coal burning power station capacity in the UK

6.2 Future developments

Future developments in the AAC sector are expected to include the use of alternative ashes to pfa where there is a business need for this, (for example, where there is not a local source of pfa). The recycled content of AAC is already high where pfa is used. The Landfill tax escalator is also expected to drive the use of new alternative raw materials as an alternative

to natural sand. The promotion of recycled content targets by WRAP are also expected to influence the uptake of alternative materials.

7. Overview roadmap for utilising alternative materials in the manufactured concrete products sector (including AAC)

7.1 Industry drivers

The following influences will be key to the pre-cast concrete manufacturing industries over the next 5-10 years:

- The Code for Sustainable Homes is a legislative requirement which sets requirements for all elements of house construction. This includes a requirement for based on the BRE Green Guide Rating[22] for key elements. It will be important for manufacturers to maintain and improve the environmental performance of their products to meet the Code requirements.
- Compulsory site waste management plans (SWMP): as a minimum, construction sites over a certain size will be required to write and implement a site waste management plan to address resource efficiency. A voluntary code has already been introduced. The introduction of compulsory SWMP's is expected to increase the demand for take-back schemes.
- The Government has specific targets that require low-impact buildings; including reducing carbon emissions by 60% by 2050 and meeting the challenges of the Code for Sustainable Homes.
- WRAP's campaign to promote recycled content in construction products (benchmark is currently a minimum of 10% recycled content by value)
- Major procurement activities (such as for the Olympics) are increasingly demanding recycled content. The Olympics materials procurement policy demands the use of products with recycled content.

Other key industry drivers for the built environment that impact on manufactured concrete products industry are set out below:

Social

- Skills gaps in the construction sector

Technological

- Modular build and off-site construction
- Thermal mass

Environmental

- Pressure on waste disposal and for recycling
- Scarcity of key construction materials
- Concern about global warming and CO₂ emissions associated with production of Portland cement
- Government estate committed to 30% reduction target for energy

- Scarcity of key construction materials

Economic

- Drive to reduce construction costs and increase speed whilst maintaining quality
- Increased global competition for resources
- Rising materials costs
- Concerns about rising costs of energy and energy security
- House price inflation puts pressure on affordability

7.2 Roadmap

There are a relatively large number of manufacturers of concrete products in the UK (more than 35). The main trade association is British Pre-cast but there are also a range of product trade associations (such as the Concrete Block Association and Autoclaved Aerated Concrete Products Association). Most of these are affiliated to or associated with British Pre-cast. The larger manufacturers have, or are developing, their own sustainability policies and agendas.

The cement industry (through the British Cement Association, BCA), is heavily committed to sustainability goals to move towards sector targets for the cement industry set by the Environment Agency for CO₂ emissions and waste. As a major source of CO₂, the cement industry is further along the road towards a sustainability agenda than the manufactured concrete product sector.

British Precast has published a visioning paper on developing a sector sustainability strategy. This is due to be completed in 2008[19]. Issues likely to emerge, in relation to this [23] include measures to:

- Recycle and reuse materials (in response to rising costs and restrictions on waste disposal)
- Reduce use of water and primary materials
- Improving market image of concrete as a “green” material

The following sustainability measures are available to the manufacturers of concrete products to meet their various sustainability agendas:

Why sustainability promotes the utilisation of alternative materials in the manufacture of concrete products

- Drive to minimise waste encourages the recycling of unavoidable production waste into the production process or other processes
- Drive to reduce the use of primary materials encourages use of residual products from other industries (leading to partial substitution of primary materials by alternative raw materials)
- Stimulates company policies to make use of recycled materials in products and to minimise waste
- Encourages water efficiency and rainwater harvesting

Higher utilisation rates of alternative raw materials can be achieved through logistics, provision of continuous supply of consistent properties and quality, which can create a greater industry demand for alternative materials

Potential benefits to the sector of using alternative raw materials in manufactured concrete product

- Material related: substitution of raw materials
- Economic: profit through charge of a gate fee
- Environmental: conservation of natural resources,
- Organisational: maintain industry's environmental profile for green products, better flexibility in raw materials sourcing
- Legal: Good practice may cause wastes to become by-products (through quality protocols)
- Social: cleaner environment, waste management, less quarrying

Potential barriers to the use of alternative raw materials in manufactured concrete products

- Material related: Logistics, continuity of supply (particle size, composition), geographical proximity, variability, undesirable properties
- Economic: Additional costs of handling, testing, trials, storage, processing requirements, monitoring, licensing, transport
- Organisational: Additional installations, corporate responsibility
- Legal: Licensing, waste transfer and storage
- Public perception of the utilisation of wastes

Future work:

Quality protocols: preparation of quality protocols for the utilisation of alternative raw materials

Key stages in the utilisation of alternative materials in the manufacture of concrete products

Milestone	Timescale	Comment
Production waste re-used in the production of concrete products	Ongoing	Already practiced widely
WRAP benchmark for recycled content	Ongoing	Currently 10% recycled content by value recommended as a minimum (by value of construction project)
Voluntary site waste management plans	Ongoing	-
EA Quality Protocol for pulverised fuel ash issued	Early 2008	Protocols re-classify material as a by-product, giving clarity over the materials standing within waste regulations and bringing clarity to its use, reducing transport and handling formalities etc
EA Quality Protocols for paper sludge ash, incinerator bottom ash being considered.	Early 2008	Protocols re-classify material as a by-product, giving clarity over the materials standing within waste regulations and bringing clarity to its use, reducing transport and handling formalities etc
Introduction of compulsory site waste management plans	April 2008	Expected to create demand for post-consumer take back schemes for construction and refurbishment waste etc.
Issue of pre-cast industry sector strategy	November 2008	Expected to define a sustainability strategy for the pre-cast concrete industry

8 References

1. WRAP AggRegain website <http://www.aggregain.org.uk/>
2. BS EN197-1: 2000 Cement: part 1: composition, specifications and conformity criteria for common cements
3. BS 3892-1:1997 Pulverized-fuel ash. Specification for pulverized-fuel ash for use with Portland cement
4. BS 3892-2:1996 Pulverized-fuel ash. Specification for pulverized-fuel ash to be used as a Type I addition
5. BS EN 450-1:2005 Fly ash for concrete. Definition, specifications and conformity criteria
6. Waste Protocols Project. Blast Furnace Slag (BFS): a technical report on the manufacturing of blast furnace slag and material status in the UK
7. British Standard Specification for Air-cooled blastfurnace slag aggregate for use in construction. BS 1047; 1983
8. WRAP, Quality Protocols for the productions of recycled aggregates from inert waste in England, Scotland and Northern Ireland, 2004 and 2005, WRAP, Banbury. Available online at www.aggregain.org.uk/quality
9. BS EN12620: 2002, aggregates for concrete
10. Petavratzi, E and Barton, J. Case study on the utilisation of alternative materials in the manufacture of common cements (Characterisation of mineral wastes, resources and processing technologies- integrated waste management for the production of construction materials.
11. BS EN 1338:2003 Concrete Paving Blocks: Requirements and test methods
12. BS EN 771-3: 2003 Specification for masonry units. Aggregate concrete masonry units (dense and light-weight aggregates)
13. BS EN 490: 2004 Concrete roofing tiles and fittings for roof covering and wall cladding. Product specifications
14. BS EN 771-4: 2003 Specification for masonry units. Autoclaved aerated concrete masonry units
15. BS EN 1916: 2002 Concrete pipes and fittings, un-reinforced, steel fibre and reinforced
16. BS EN 1168: 2005 Precast concrete products. Hollow core slabs
17. DTI monthly statistics of building materials and components. February 2007. <http://www.berr.gov.uk/files/file41310.pdf>
18. National Statistics Product Sales and Trading. PRA 26610. Concrete Products for Construction Purposes, 2006.
19. Holton I.R. and Glass, J et al. developing a sector sustainability strategy. BIBM International Conference, 2005. Extended abstract <http://www.britishprecast.org/sustainableprecast/downloads/BIBM-Congress2005-Extended-abs21.pdf>
20. Byars, E.A. Morales, B and Yu, H ConglassCrete II. Final report <http://www.wrap.org.uk/downloads/ConGlassCrete2FinalBodyi.73c5baac.pdf>
21. Quillin, K, Calcium sulfoaluminate cements: CO₂ reduction, concrete properties and applications.
22. The Green Guide to Specification 3rd Edition. Blackwell, 2002
23. British Precast: Sustainability matters. <http://www.britishprecast.org/documents/SustainabilityMatters06.pdf>

Websites

British Precast - <http://www.britishprecast.org/index.php>
British Cement Association - <http://www.cementindustry.co.uk/>
Concrete Block Association - <http://www.cba-blocks.org.uk/>
Aircrete Products Association - <http://www.aircrete.co.uk/>
The Concrete Centre - <http://www.concretecentre.com/main.asp?page=0>