20/05/2015

Proposal for inclusion of a new source material in to the inventory list with classification codes for source materials – Table A2 of Annex A EN13055:2014(E)

It may also be considered if the committee deems appropriate to include within EN 13242 Annex A as a manufactured aggregate.

Summary

The following information is submitted in a format requested in the Draft Standard FprEN 13055:2014(E)

It is recognised that the standard is not currently published and active, however it is prudent to make the application to CEN/TC 154 for the following reasons.

- Current users of the aggregate use such certification in their quality and environmental management systems
- Any interruption in the continued ability to certify to a EN standard could have serious commercial impacts resulting in a potential legal challenge

<table>
<thead>
<tr>
<th>Subject</th>
<th>General Information Given by Applicant</th>
<th>Reference to Annex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member State</td>
<td>UK</td>
<td></td>
</tr>
<tr>
<td>Definition</td>
<td>Aggregate manufactured by use of Accelerated Carbonation Technology, raw materials are thermal residues e.g Fly Ash &amp; Air Pollution Control residue from Waste to Energy plants</td>
<td></td>
</tr>
<tr>
<td>Field of Application</td>
<td>BS EN 13055:2014 Table A.2 - Source Material ; Manufactured Aggregate from industrial processes or recycled source materials Positive history of uses - U1, U2, U3, U4</td>
<td>Annex A</td>
</tr>
<tr>
<td>Technical Information</td>
<td>See following Attached; Ref Doc 1 Carbon8 Aggregates Data sheet 1 Ref Doc 2 Carbon8 Aggregates Data sheet 2 Ref Doc 3 Carbon8 Aggregates Data sheet 3</td>
<td></td>
</tr>
</tbody>
</table>
| Experience/quantity/ demonstration | Ref Doc 4  
Carbon8 Aggregates Data sheet 4  
Ref Doc 5  
CE Mark Certificate  
Ref Doc 6  
ISOQAR – Certificates |
|------------------------------------|--------------------------------------------------|
| Experience/quantity/ demonstration | Ref Doc 7  
Ref Doc 8:  
Production of lightweight aggregate from industrial waste and carbon dioxide.  
Ref Doc 9:  
Gunning, P.J., Hills, C.D., and Carey, P.J. 2013 The first commercial application of accelerated carbonation; looking back at the first year.  
Ref Doc 10:  
Ref Doc 11  
Lignacite Carbon Buster data sheet  
Ref Doc 12  
Manufacturer’s Statement on experience quantity & demonstration |
| Criteria used to control the quality of the material | Ref Doc 6  
ISOQAR – Certificates |
Carbon8 Aggregates Ltd 

Technical Data Sheet 1 – C8A Block Mix

Carbon8 Aggregates Ltd is using an award winning, patented process known as accelerated carbonation technology (ACT) to manufacture a lightweight aggregate, C8 Aggregate (C8A). The accelerated carbonation process captures more carbon dioxide than is used to run the plant, making C8A the world’s first carbon negative aggregate. C8A is manufactured under a strict Quality System in compliance with ISO 14001, 9001 and OHSAS 18001, and all products can be CE marked in accordance with EN 13055, the standard for lightweight aggregates.

C8A Block Mix is an ideal material for incorporation into concrete masonry blocks. Some key benefits are:

- Density
- Strength
- Consistent quality
- Reliability of supply
- Carbon negative

C8A is a quality controlled, manufactured product that:
- Is manufactured using a patented process which converts a waste into a high quality product
- ‘End of Waste’ specification approved by the Environment Agency (2011)
- Uses CO₂ that would otherwise be emitted to the atmosphere
- Reduces greenhouse gas emissions, helping reduce climate change
- Reduces vehicle movements as a greater volume can be moved for same tonnage
- Saves on the exploitation of natural resources

For further information contact Carbon8 Aggregates at www.c8a.co.uk info@c8a.co.uk Tel: 01634 264582
C8A Block Mix Properties

C8 Aggregate is a grey sub-rounded, homogeneous, lightweight aggregate, with a rough surface, that can be used for a variety of applications and is tested in accordance with EN 13055-1 (2002)

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Value</th>
<th>Unit</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>0 - 15</td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Dry loose bulk density</td>
<td>Minimum 950</td>
<td>kg/m³</td>
<td>EN 1097</td>
</tr>
<tr>
<td></td>
<td>Maximum 1100</td>
<td>kg/m³</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Particle density</td>
<td>Oven dried 1.94</td>
<td>kg/m³</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Crushing Resistance</td>
<td>Typical value 6.6</td>
<td>N/mm²</td>
<td>EN 13055</td>
</tr>
<tr>
<td></td>
<td>Minimum value 5.2</td>
<td>N/mm²</td>
<td>EN 13055</td>
</tr>
<tr>
<td>Moisture content as delivered</td>
<td>Typical value 8</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Water absorption</td>
<td>18.8</td>
<td>%</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Water soluble chloride</td>
<td>4.2</td>
<td>%</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Water soluble sulfate</td>
<td>0.1</td>
<td>%</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Total sulfate (as SO₃)</td>
<td>1.78</td>
<td>%</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Resistance to Attrition (Los Angeles)</td>
<td>39</td>
<td>%</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Magnesium sulphate soundness</td>
<td>30.1</td>
<td>%</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>0.021</td>
<td>%</td>
<td>EN 1367</td>
</tr>
</tbody>
</table>

C8Agg Specification

(Leaching in accordance with EN 12457 in mg/kg, bdl = below detection limit)
(Max = Specification agreed with the Environment Agency)
(Aver = Average levels for C8Agg)

<table>
<thead>
<tr>
<th>Sb</th>
<th>As</th>
<th>Ba</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Pb</th>
<th>Mo</th>
<th>Ni</th>
<th>Se</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>0.06</td>
<td>0.5</td>
<td>50</td>
<td>0.04</td>
<td>1.5</td>
<td>0.15</td>
<td>0.5</td>
<td>1.0</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Aver</td>
<td>bdl</td>
<td>0.05</td>
<td>17</td>
<td>bdl</td>
<td>0.5</td>
<td>bdl</td>
<td>0.1</td>
<td>0.2</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

*Carbon8 Aggregate (C8A) should only be used for applications relevant to the product standard and specification under which the products are sold. Carbon8 Aggregates Ltd cannot be held responsible if products are used for applications inappropriate to the product specification. If in any doubt please contact the company before use. Our terms and conditions of sale apply to all products.*

C8A Block Mix 16.02.15
Carbon8 Aggregates Ltd

Technical Data Sheet 2 – C8A RM for Ready Mix Concrete

Carbon8 Aggregates Ltd is using an award winning, patented process known as accelerated carbonation technology (ACT) to manufacture a lightweight aggregate, C8 Aggregate (C8A). The accelerated carbonation process captures more carbon dioxide than is used to run the plant, making C8A the world’s first carbon negative aggregate. C8A is manufactured under a strict Quality System in compliance with ISO 14001, 9001 and OHSAS 18001, and all products can be CE marked in accordance with EN 13055, the standard for lightweight aggregates.

C8A RM is suitable for use in all ready mix concrete applications where there is no steel reinforcement embedded in the cast concrete. C8A RM may be used in combination with natural or other secondary aggregates.

Some key benefits are:

• Carbon negative
• Low density

• Suitable for use with fibre reinforcement
• Consistent quality
• Reliability of supply
• Range of gradings available

C8A is a quality controlled, manufactured product that:

• Is manufactured using a patented process which converts a waste into a high quality product
• Uses CO₂ that would otherwise be emitted to the atmosphere
• Reduces greenhouse gas emissions, helping reduce climate change
• Reduces vehicle movements as a greater volume can be moved for same tonnage
• Saves on the exploitation of natural resources

For further information contact Carbon8 Aggregates at
www.c8a.co.uk info@c8a.co.uk Tel: 01634 264582
C8A RM Properties

C8 Aggregate is a grey sub-rounded, homogeneous, lightweight aggregate, with a rough surface, that can be used for a variety of applications and is tested in accordance with EN 13055-1 (2002)

<table>
<thead>
<tr>
<th>Material Properties</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>4 - 16 mm</td>
<td></td>
</tr>
<tr>
<td>Dry loose bulk density</td>
<td>Minimum 950 kg/m$^3$ EN 1097</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum 1100 kg/m$^3$ EN 1097</td>
<td></td>
</tr>
<tr>
<td>Particle density</td>
<td>Oven dried 1.94 kg/m$^3$ EN 1097</td>
<td></td>
</tr>
<tr>
<td>Crushing Resistance</td>
<td>Typical value 6.6 N/mm$^2$ EN 13055</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum value 5.2 N/mm$^2$ EN 13055</td>
<td></td>
</tr>
<tr>
<td>Moisture content as delivered</td>
<td>Typical value 8% EN 1097</td>
<td></td>
</tr>
<tr>
<td>Water absorption</td>
<td>18.8% EN 1097</td>
<td></td>
</tr>
<tr>
<td>Water soluble chloride</td>
<td>4.2% EN 1744</td>
<td></td>
</tr>
<tr>
<td>Water soluble sulphate</td>
<td>0.1% EN 1744</td>
<td></td>
</tr>
<tr>
<td>Magnesium sulphate soundness</td>
<td>30.1% EN 1097</td>
<td></td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>0.021% EN 1367</td>
<td></td>
</tr>
</tbody>
</table>

Typical Applications

- Trench Fill Foundation
- Fibre Reinforced concrete
- Pipe Haunching
- Kerb Haunching
- Oversites
- Mass concrete blocks

Carbon8 Aggregate (C8A) should only be used for applications relevant to the product standard and specification under which the products are sold. Carbon8 Aggregates Ltd cannot be held responsible if products are used for applications inappropriate to the product specification. If in any doubt please contact the company before use. Our terms and conditions of sale apply to all products.

C8A RM 15.02.15
Carbon8 Aggregates Ltd

Technical Data Sheet 3 – C8A PC for Precast Concrete

Carbon8 Aggregates Ltd is using an award winning, patented process known as accelerated carbonation technology (ACT) to manufacture a lightweight aggregate, C8 Aggregate (C8A). The accelerated carbonation process captures more carbon dioxide than is used to run the plant, making C8A the world’s first carbon negative aggregate. C8A is manufactured under a strict Quality System in compliance with ISO 14001, 9001 and OHSAS 18001, and all products can be CE marked in accordance with EN 13055, the standard for lightweight aggregates.

C8A PC is suitable for use in all precast concrete applications where there is no steel reinforcement embedded in the cast concrete. C8A PC may be used in combination with natural or other secondary aggregates.

Some key benefits are:

- Carbon negative
- Low density
- Suitable for use with fibre reinforcement
- Consistent quality
- Reliability of supply
- Range of gradings available

C8A is a quality controlled, manufactured product that:

- Is manufactured using a patented process which converts a waste into a high quality product
- Uses CO₂ that would otherwise be emitted to the atmosphere
- Reduces greenhouse gas emissions, helping reduce climate change
- Reduces vehicle movements as a greater volume can be moved for same tonnage
- Saves on the exploitation of natural resources

For further information contact Carbon8 Aggregates at
www.c8a.co.uk info@c8a.co.uk Tel: 01634 264582
C8A PC Properties

C8 Aggregate is a grey sub-rounded, homogeneous, lightweight aggregate, with a rough surface, that can be used for a variety of applications and has been tested in accordance with EN 13055-1 (2002)

<table>
<thead>
<tr>
<th>Material Properties</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry loose bulk density</td>
<td>Minimum</td>
<td>950 kg/m³</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>1100 kg/m³</td>
</tr>
<tr>
<td>Particle density</td>
<td>Oven dried</td>
<td>1.94 kg/m³</td>
</tr>
<tr>
<td>Crushing Resistance</td>
<td>Typical value</td>
<td>6.6 N/mm²</td>
</tr>
<tr>
<td>Moisture content as delivered</td>
<td>Typical value</td>
<td>8 %</td>
</tr>
<tr>
<td>Water absorption</td>
<td>18.8 %</td>
<td></td>
</tr>
<tr>
<td>Water soluble chloride</td>
<td>4.2 %</td>
<td></td>
</tr>
<tr>
<td>Water soluble sulphate</td>
<td>0.1 %</td>
<td></td>
</tr>
<tr>
<td>Resistance to attrition (Los Angeles)</td>
<td>48 %</td>
<td></td>
</tr>
<tr>
<td>Magnesium sulphate soundness</td>
<td>30.1 %</td>
<td></td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>0.021 %</td>
<td></td>
</tr>
</tbody>
</table>

Typical Applications

- Concrete “Lego” Blocks
- Fibre reinforced units
- Ornamental precast
- Street furniture
- Gullies and troughs
- Flags and Kerbs

*Carbon8 Aggregate (C8A) should only be used for applications relevant to the product standard and specification under which the products are sold. Carbon8 Aggregates Ltd cannot be held responsible if products are used for applications inappropriate to the product specification. If in any doubt please contact the company before use. Our terms and conditions of sale apply to all products.*
Carbon8 Aggregates Ltd

Technical Data Sheet 4 – C8A NF Screed System

Carbon8 Aggregates Ltd is using an award winning, patented process known as accelerated carbonation technology (ACT) to manufacture a lightweight aggregate, C8 Aggregate (C8A). The accelerated carbonation process captures more carbon dioxide than is used to run the plant, making C8A the world’s first carbon negative aggregate. C8A is manufactured under a strict Quality System in compliance with ISO 14001, 9001 and OHSAS 18001, and all products can be CE marked in accordance with EN 13055, the standard for lightweight aggregates.

C8A NF is an ideal material for use in No-Fines Screeding Systems, C8A is only supplied to a limited number of screeding companies who understand and are competent in the application of the C8A NF screed system.

The benefits of the system are:

- Low carbon footprint
- Low density
- Thermal insulation
- Low shrinkage
- Consistent quality
- Reliability of supply
- Screed complies to EN 8204

C8A is a quality controlled, manufactured product that:

- Is manufactured using a patented process which converts a waste into a high quality product
- Uses CO\textsubscript{2} that would otherwise be emitted to the atmosphere
- Reduces greenhouse gas emissions, helping reduce climate change
- Reduces vehicle movements as a greater volume can be moved for same tonnage
- Saves on the exploitation of natural resources

For further information contact Carbon8 Aggregates at www.c8a.co.uk info@c8a.co.uk Tel: 01634 264582
C8A NF Screed Properties

<table>
<thead>
<tr>
<th>No fines base</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density</td>
<td>1436 kg/m³</td>
</tr>
<tr>
<td>Weight per sq m at 100mm thick</td>
<td>143.6 kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System: 100mm base and 15 mm topping</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density</td>
<td>1510 kg/m³</td>
</tr>
<tr>
<td>Weight per sq m</td>
<td>173.7 kg</td>
</tr>
<tr>
<td>Kg of CO2 per sq m</td>
<td>11 kg</td>
</tr>
</tbody>
</table>

C8A no-fines levelling Screed System is generally used where category B or C in-situ crushing resistance (ISCR) is required. In order to achieve category A, particular attention should be given to the thickness and type of topping.

Advantages of C8A NF Screed System

- More sustainable solution to screed flooring; needs significantly less cement, less insulation and uses a carbon negative aggregate, manufactured from waste.
- Carbon footprint per square metre half that of a standard concrete screed.
- Good thermal properties mean less expensive non-sustainable polymer insulation is required.
- The free passage of air through the C8A NF ensures a quicker drying rate than with standard sand/cement screed.

Carbon8 Aggregate (C8A) should only be used for applications relevant to the product standard and specification under which the products are sold. Carbon8 Aggregates Ltd cannot be held responsible if products are used for applications inappropriate to the product specification. If in any doubt please contact us before use. Our terms and conditions of sale apply to all products.
CERTIFICATE OF REGISTRATION

ISOQAR

This is to certify that the Management System of:

Carbon8 Aggregates Limited
c/o Lignacite, Norfolk House,
High Street, Brandon, Suffolk, IP27 0AX

has been approved by ISOQAR

11259
ISO 14001: 2004

Scope of Activities:
The Manufacture of Aggregates from Waste.

Certificate Number: 11259-EMS - 001
Initial Registration Date: 23 August 2013
Expiry Date: 23 August 2016

Signed by:
Lee Pearson, Managing Director
(on behalf of ISOQAR)

This certificate will remain current subject to the company maintaining its system to the required standard. This will be monitored regularly by ISOQAR. Further clarification regarding the scope of this certificate and the applicability of the relevant standards' requirements may be obtained by consulting ISOQAR Ltd. This certificate is one of several issued to registration number 11259.

ISOQAR Limited Cobra Court, 1 Blackmore Road, Stretford, Manchester M32 0QY
T: +44 (0)161 865 3699  F: +44 (0)161 865 3685  E: enquiries@isoqar.com  www.isoqar.com
This certificate is the property of ISOQAR and must be returned on request.
CERTIFICATE OF REGISTRATION

ISOQAR

This is to certify that the Management System of:

Carbon8 Aggregates Limited
c/o Lignacite, Norfolk House,
High Street, Brandon, Suffolk, IP27 0AX

has been approved by ISOQAR

11259

BS OHSAS 18001 2007

Scope of Activities:
The Manufacture of Aggregates from Waste.

Certificate Number: 11259-HAS - 001
Initial Registration Date: 23 August 2013
Expiry Date: 23 August 2016

Signed by:
Lee Pearson, Managing Director
(on behalf of ISOQAR)

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High Street, Brandon, Suffolk, IP27 0AX

has been approved by ISOQAR

11259
ISO 9001: 2008

Scope of Activities:
The Manufacture of Aggregates from Waste.

Certificate Number: 11259-QMS - 001
Initial Registration Date: 23 August 2013
Expiry Date: 23 August 2016

Signed by:
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(on behalf of ISOQAR)

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Abstract

As a result of the EU Landfill Directive, the disposal of municipal solid waste incineration (MSWI) fly ash is restricted to only a few landfill sites in the UK. Alternative options for the management of fly ash, such as sintering, vitrification or stabilization/solidification, are either costly or not fully developed. In this paper an accelerated carbonation step is investigated for use with fly ash. The carbonation reaction involving fly ash was found to be optimum at a water/solid ratio of 0.3 under ambient temperature conditions. The study of ash mineralogy showed the disappearance of lime/portlandite/calcium chloride hydroxide and the formation of calcite as carbonation proceeded. The leaching properties of carbonated ash were examined. Release of soluble salts, such as SO$_4$, Cl, was reduced after carbonation, but is still higher than the landfill acceptance limits for hazardous waste. It was also found that carbonation had a significant influence on lead leachability. The lead release from carbonated ash, with the exception of one of the fly ashes studied, was reduced by 2–3 orders of magnitude.

1. Introduction

The increasing amount of municipal waste produced is a worldwide environmental problem and incineration is a popular management option, particularly where recycling or reuse are not possible (European Union, 1999). Incineration can be used to recover energy and reduce the mass and volume of waste by 70% and 90%, respectively, and the ash produced can be recycled or disposed of to landfill. Currently, there are 13 incinerators in the UK with a total processing capacity of 2.9 million tons per year. During the incineration process, the hot gases produced from the waste burn are used to generate electricity and/or heat. The flue gas is treated with dry, wet or semi-dry lime and activated carbon for the removal of acid gases such as NO$_x$, SO$_x$ and CO$_2$ to meet emission targets. Two categories of solid residues are produced in incinerator: bottom ash and air pollution control (APC) residues. Bottom ash is a heterogeneous mixture of slag, metals, ceramics, glass, other non-combustibles and unburned organics, whilst the APC residues are fine particulates collected by the air treatment systems, and are a mixture of fly ash, lime and carbon. Usually APC residues and fly ash are interchangeable.

Fly ash is generally classified as hazardous waste according to the European Waste Catalogue (European Union, 2000; SEPA, 2003) because of the high levels of soluble salts and heavy metals such as cadmium, lead and zinc. The presence of lime also gives fly ash a high alkalinity, resulting in an increased potential for leaching, which is important when landfill is concerned.

The Incineration Directive (EU 2000/76/EC) has resulted in more stringent controls on gaseous emissions from incineration, so that more hazardous compounds will be retained in the solid residues. It has been reported that 314,000 tonnes of fly ash were produced in the UK during 1996–2000, of which nearly 90% was sent to landfill (Environment Agency, 2002). However, the implementation of the EU landfill Directive (EU, 1999/31/EC) has dramatically reduced the availability of landfill space for these hazardous wastes. Since July 2004, the number of sites registered to accept hazardous wastes has decreased from
over 200 to less than 10. In addition, the UK government is increasing the standard rate of landfill tax by at least €4.4/1000 kg each year from €22/1000 kg in 2005 in order to encourage the reuse and recycling of waste. The long-term rate of the tax is €51/1000 kg (HM Treasury Budget, 2003). Therefore, the disposal of MSWI fly ash is becoming an increasingly costly management option.

There have been a number of research projects examining the disposal of MSWI ash (Polettini et al., 2001, 2004; Sakai and Hiraoka, 2000; Mangialardi, 2001, 2003; Mizutani et al., 2000; Mulder, 1996). The main techniques currently under investigation, or in use, are thermal treatment, stabilization/solidification (S/S) and washing-immobilization processes. Thermal treatment, such as sintering or vitrification (Mangialardi, 2001; Polettini et al., 2004), is costly and not widely used. The sintered residues are more hazardous than the untreated fly ash and become more difficult to dispose of (Sakai and Hiraoka, 2000). So far this technology is only used in a few countries, such as Japan, Korea and Sweden (Ecke et al., 2000). The S/S process employs cement or other chemical agents (such as furnace slag and soluble phosphate) to immobilize the contaminants (Eighmy et al., 1997). It is one of the most commonly used processes for the treatment of solid waste, sludge and contaminated soil (Polettini et al., 2001; Mizutani et al., 2000; Environment Agency, 2004). New mineral phases are generated during the process and the leaching properties of the waste are changed. S/S, however, may increase the mass and volume of the wastes leading to an extra cost of transportation and disposal. Alternatively, the contaminants in fly ash can be removed by washing (Mangialardi, 2003; Mulder, 1996). Water or acid is used as solvent and most of the hazardous compounds, i.e., soluble salts and heavy metals, are dissolved. Further steps are then followed to treat the leached residues. A major concern with this technique is the large amount of wastewater generated.

Alternatively, many researchers have been investigating the natural or accelerated aging of bottom ash, a process which could also be applied to fly ash disposal. Bottom ash can be used as a secondary construction material after several weeks of natural weathering in landfill sites (Environment Agency, 2002). It is known that a series of physical and chemical changes take place during natural weathering including hydrolysis, hydration, precipitation/dissolution, oxidation/reduction and carbonation (Meima and Comans, 1997, 1999; Sabbas et al., 2003). Polettini et al. (2003) claimed that treatment of bottom ash using CO$_2$, i.e., so called accelerated aging, can result in improved mineralogical, chemical and leaching properties. It has been shown that the formation of carbonate was one of the major changes affecting the leaching behaviour and acid neutralization capacity of the bottom ash (Chimenos et al., 2000).

Therefore, aging and weathering are known to affect the mineralogy, chemical and leaching properties, particularly the immobilization of heavy metals in waste and allow the mature properties of the ash to develop. Accelerated carbonation may accelerate these natural reactions. In this paper, an accelerated carbonation treatment is proposed for the treatment of MSWI fly ash. The carbonation of fly ash was investigated and optimized, and the changes to mineralogy and leaching behaviour were examined.

The use of carbon dioxide in a treatment step for both bottom ash and fly ash would have the added environmental benefit of the permanent sequestration of carbon dioxide and open up the possibility of trading in carbon credits for the incineration companies.

### 2. Experiments and analysis

The ash samples were supplied by the Environment Agency and three incinerators in the UK. Their properties and the typical components of ash are listed in Tables 1 and 2. The ash was divided into two parts. One part was subdivided further for analysis. The other was treated by carbonation. The analysis of untreated and carbonated ash included moisture content, carbonate content, mineralogy, pH and leaching test.

#### 2.1. Reaction procedure

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### Table 1

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Source</th>
<th>Water content</th>
</tr>
</thead>
<tbody>
<tr>
<td>EA FA1-3</td>
<td>Environment Agency, UK</td>
<td>0–2.5%</td>
</tr>
<tr>
<td>SE FA</td>
<td>SELCHP, Lewisham, London</td>
<td>0.5%</td>
</tr>
<tr>
<td>CL FA</td>
<td>Cleveland Incinerator, UK</td>
<td>0.7%</td>
</tr>
<tr>
<td>KI FA</td>
<td>Kirklees Incinerator, UK</td>
<td>0.35%</td>
</tr>
</tbody>
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### Table 2

<table>
<thead>
<tr>
<th>Elements</th>
<th>Amount (%)</th>
</tr>
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<tbody>
<tr>
<td>CaO</td>
<td>36.268</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>1.054</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>2.034</td>
</tr>
<tr>
<td>TiO</td>
<td>0.526</td>
</tr>
<tr>
<td>MnO</td>
<td>0.036</td>
</tr>
<tr>
<td>Pb</td>
<td>0.303</td>
</tr>
<tr>
<td>Ba</td>
<td>0.032</td>
</tr>
<tr>
<td>Zn</td>
<td>0.752</td>
</tr>
<tr>
<td>Cu</td>
<td>0.053</td>
</tr>
<tr>
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Before carbonation, the ashes were dried at 105 °C to constant weight and then mixed with water before being placed into the reactor. For each set of experiments, control samples were prepared in the same manner and then sealed and stored under ambient laboratory conditions for the same time period. The extent of the reaction of the ash with CO₂ was assessed by measuring the gain in weight between the initial dry powder and the dried product, being proportional to the amount of CO₂ that had combined with the sample. The measured value was compared to the weight gain experienced by the control sample.

To examine the influence of reaction temperature on the carbonation, the ashes were mixed with water and then placed in the reactor in a uniform layer of 3 mm. The reactor was closed tightly and filled up to a pressure of 3 bar with a 1:1 mixture of dry CO₂ and N₂. The reaction temperature was controlled by a cooling system. The pressure of CO₂ in the reactor was measured and used to calculate the consumption of CO₂ gas (in moles) by the ash.

To investigate the influence of water to solid ratio (w/s), values from 0.1 to 0.8 on carbonation were studied. Samples of fly ash (5 g) were carbonated for 3 h by exposing the ash to a 100% CO₂ atmosphere at 75% relative humidity and at a pressure of 3 bar. A saturated solution of NaCl was used to maintain a constant relative humidity in the chamber. The weight gain of the dry SELCHP ash was measured in triplicate.

Following these initial trials, the ash was carbonated in the closed chamber for 3 days at 3 bar pressure of CO₂ and a relative humidity of 75%. The samples were then dried in order to examine the carbonate content, mineralogy and leaching properties.

2.2. Analytical methods

The moisture content was measured after heating in an oven at 105 °C (BS 1377-2, 1990). The carbonate content was calculated from the weight loss on ignition between 450 °C and 900 °C. Thermogravimetric and differential thermal analysis (TG/DTA) of carbonated ash was performed with a Stanton Redcroft STA-780 thermo analyzer in a temperature range of 20–1100 °C at a heating rate of 10 °C/min. Mineral phases in ashes were determined by X-ray powder diffraction. The pH was examined according to BS 1377 part 3:1990.

The compliance leaching test was carried out in accordance to British Standard BS EN12457: 2002, which is designed to examine the short-term and long-term leaching behaviour for landfills. It is a two-step leaching test with liquid/solid = 10 L/kg. The ash was leached at L/S = 2 L/kg for 6 h of end-over-end mixing and then filtered. The residues were leached further at L/S = 8 L/kg for 18 h. The eluate was filtered with a 0.45 µm filter paper and then divided into two solutions. One sample was measured by Ion-Chromatography (DIONEX) for the chloride and sulfate content. The other was acidified with nitric acid to pH < 2 for elemental analysis. The concentration of the major elements Al, Ca, K, Na and minor elements As, Ba, Cd, Cr, Cu, Fe, Pb, Ni, Zn in leachate were analyzed by ICP-OES (Horizontal). All analyses were carried out in triplicate.

3. Results and discussion

3.1. Carbonation conditions

The variables that have influence on the reaction, such as water/solid ratio, reaction temperature, reaction time, etc., were studied in this project. Previous work about the influence of reaction time and particle size has been published (Fernandez Bertos et al., 2004b).

The carbonation mechanism can be considered a sequential reaction expressed by the following equations (Freyssinet et al., 2002):

\[
\begin{align*}
H_2O + CO_2 &\rightarrow H_2CO_3 \\
H_2CO_3 &\rightarrow H^+ + HCO_3^- \rightarrow 2H^+ + CO_3^{2-} \\
Ca^{2+} + CO_3^{2-} &\rightarrow CaCO_3
\end{align*}
\]

It is known that water is necessary to promote the reaction of CO₂, but too much water limits the reaction due to the blockage of the pores in the solid (Fernandez Bertos et al., 2004a). Hydration and dissolution of CO₂ occur in the presence of water, as well as the dissolution of Ca²⁺ ions from the solid phase, which reacts with the CO₂ to form calcium carbonate. At low water–solid ratios, the gas permeability is high and the CO₂ effectively diffuses into the material. However, with the increase in water content, the pores in the ash are effectively sealed off. The diffusion of gas into the pore system is hindered, inhibiting the reaction.

The results of reaction with different w/s ratios are shown in Fig. 1. The optimum w/s ratio is 0.3 by weight of ash. However, some authors found the optimum ratio for the carbonation of cementitious systems to be between w/s 0.06 and 0.20 (Asavapisit et al., 1997; Klemm and...
Berger, 1972) and others have successfully carbonated with values up to 0.35 (Yousuf et al., 1993).

The conversion at different temperatures is shown in Fig. 2, which shows the evolution of the reaction with time. As expected, the reaction proceeded more quickly at the beginning and then slowed down. The initial speed of reaction is higher at higher temperatures, although the final conversion achieved is lower. The opposite is the case at lower temperature. The highest weight gain is observed at 21 °C. Consequently, the following reactions were carried out at ambient temperature condition.

3.2. CO₂ uptake and carbonate content

As in the carbonation mechanism mentioned above, carbonate salts were formed during reaction. The DTA curve, shown in Fig. 3, indicates that the loss of pore water in carbonated ash occurred under 200 °C, and the decomposition of calcium carbonate happens between 450 and 850 °C. So the weight loss between 450 and 900 °C was considered to be the carbonate content of the sample. The combustion of organics happens between 300 and 450 °C, as is characterised by a positive ΔT peak (Johnson et al., 2003).

As previously explained, the extent of carbonation was also assessed by measuring the gain in dry weight before and after the reaction. However, there is a difference between the weight gain recorded and the carbonate as determined by the TG/DTA. The gain in weight is greater than can be explained by the observed increase in carbonate content, suggesting that other reaction products are being generated. Fig. 4 shows the CO₂ uptake and the carbonate content increase of ashes. The individual fly ashes react with CO₂, by different amounts within the range of 2–7% by weight.

3.3. Mineral phases in ash

X-ray diffractograms of the ashes are shown in Fig. 5 and were used to determine the mineralogical changes that took place during carbonation. Table 3 lists the main mineral phases found in ash.

The most obvious differences between the diffractograms of original and carbonated samples are the increase in calcite peak intensity and the reduction of the lime/portlandite/Ca(OH)Cl peaks. Untreated ash contains lime/portlandite and calcium chloride hydroxide (Ca(OH)Cl), as the result of lime addition during gas treatment. These phases disappear after carbonation. There were also many Si–Al–Ca salts identified in the carbonated ashes, including gehlenite, braunite and larnite. For Kirklees fly ash, hydrated products, such as gehlenite, were also found after carbonation. So the difference of weight gain and carbon-

![Fig. 2. Evolution of reaction at different temperatures.](image-url)

![Fig. 3. TG/DTA curve of carbonated SELCHP fly ash.](image-url)

![Fig. 4. Weight gain during reaction for the various fly ashes.](image-url)

![Fig. 5. XRD diffractograms of original and carbonated fly ash.](image-url)
ate content above could be explained by hydration occurring at the same time as carbonation. It should be noted that there are many chloride bearing phases, such as halite, sylvite and Ca(OH)Cl, in ash. These phases are the main components releasing chloride in leachates (Bodenan and Deniard, 2003) and their high solubility leads to high concentrations of chloride in ash leachates.

### 3.4. PH of ashes

Due to the existence of lime, MSWI fly ash is highly alkaline, which is detrimental to its reuse. After carbonation, however, the alkalinity of ash is expected to be reduced as the calcium oxide is transformed to calcium carbonate. Fig. 6 shows the pH change after carbonation.

The original pH of ash is around 12–12.5, which is very close to the pH of a solution saturated in portlandite. The alkalinity of aged ashes from the Environment Agency is slightly lower than fresh ash, which may be the result of natural aging. After carbonation, the pH of these aged ashes was lowered to 7–10. The pH drop of fresh ash is, to a large extent, related to their carbonation reactivity, i.e., the amount of CO$_2$ sequestered. With higher activity, the carbonated SELCHP ash and Kirklees ash show a lower pH at around 7, compared with only a slight drop in the pH of the Cleveland ash. Therefore, accelerated carbonation has a major influence on ash pH.

### 3.5. Leaching properties

One of the most important criteria for disposal to landfill or reuse of wastes is the release of hazardous compounds to the surrounding environment. The Landfill (England and Wales) Regulation, 2004 (Statutory Instrument, 2004) gives criteria for waste landfills, in which the wastes sent to landfill are classified into three categories, ‘non-hazardous’, ‘hazardous’ and ‘inert’ in terms of their leachability and stability. The limit values for landfill are given in Table 4. To determine which elements are of concern, the leachability of metals, such as As, Ba, Cd, Cr, Cu, Mo, Ni, Pb, Zn, and soluble salts Cl, SO$_4$ from untreated and carbonated SELCHP ash were analyzed. The release of Cl, SO$_4$, Cd, Cr, Cu, Pb and Zn from the original ash was over the landfill limit values and should be considered.

#### 3.5.1. Soluble salts in leachate

Sulfate and chloride are the main soluble salts released from ash. The existence of large amounts of these salts in fly ash has a major influence on the setting and hydration of cement (Taylor, 1990).

From the mineralogical analysis of ash, the chloride ions occur in halite and sylvite, both of which are highly soluble. As the result, chloride release from fly ash is much higher than the acceptance value for hazardous wastes (Table 4) as shown in Fig. 7. Although carbonation reduced the chloride mobility, it was still higher than the acceptance value.

Sulfate content in the leachate is under the limit for non-hazardous wastes for all of the ash samples. The sulfate concentration was lower after carbonation as shown in Fig. 8. There was no obvious correlation between ash carbonation reactivity and leachable sulfate.

#### 3.5.2. Heavy metals release

The concentrations of Ca, Na and K in leachates are very high and result from the high solubility of minerals bearing these elements, such as halite and sylvite. The release of other elements, with the exception of Cd, Pb and Zn, was under the limit value for non-hazardous waste. Figs. 9–11 show the change in the release of Cd, Pb and Zn. Table 4 gives the limit value from the landfill accep-

---

**Table 3**

Main mineral phases in ash

<table>
<thead>
<tr>
<th>Mineral phases</th>
<th>Formula</th>
<th>Untreated</th>
<th>Carbonated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>CaO</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Portlandite</td>
<td>Ca(OH)$_2$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>Ca(OH)Cl</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Quartz</td>
<td>SiO$_2$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>CaSO$_4$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Halite</td>
<td>NaCl</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sylvite</td>
<td>KCl</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Friedels salt</td>
<td>Ca$_2$Al(OH)$_3$Cl(H$_2$O)$_3$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Nordstrandite</td>
<td>Al(OH)$_3$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Calcite/vaterite</td>
<td>CaCO$_3$</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Gehlenite</td>
<td>Ca$_2$Al$_2$SiO$_7$</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

---

**Table 4**

Leaching limit values for the acceptance of wastes in landfills (mg/kg)

<table>
<thead>
<tr>
<th>Components</th>
<th>Hazardous waste</th>
<th>Non-hazardous waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Cr total</td>
<td>70</td>
<td>10</td>
</tr>
<tr>
<td>Cu</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Ni</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Pb</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Zn</td>
<td>200</td>
<td>50</td>
</tr>
<tr>
<td>Cl</td>
<td>25,000</td>
<td>15,000</td>
</tr>
<tr>
<td>SO$_4$</td>
<td>50,000</td>
<td>20,000</td>
</tr>
</tbody>
</table>

---

Fig. 6. pH value of original and carbonated ash.
tance criteria. Cadmium release from the majority of ashes was lower than the limit value for hazardous wastes (1 mg/kg) but higher than that for non-hazardous wastes (0.1 mg/kg). No obvious relationship between carbonation and cadmium mobility was found. However, it should be noted that for the fly ashes SE FA and KI FA, leachable Cd increased after carbonation. This may result from an increase in cadmium solubility at lower pH (West General Incorporated).

Lead release from all of the ashes decreased dramatically with carbonation. The lead concentration in almost all of the untreated ash leachate was much higher than the landfill acceptance value, but after carbonation it was reduced 2–3 orders of magnitudes to lower than 6 mg/kg, with the exception of CL FA.

The change of zinc mobility is more complicated. The zinc release from the carbonated aged ash provided by the Environment Agency was reduced by 1–2 orders of magnitude. For the fresh ashes, some showed only slight change, and in KI FA the zinc is mobilized after carbonation.

4. Conclusions

The fly ash could combine with 7–10% w/w of carbon dioxide during accelerated carbonation. Water/solid ratio and temperature have a major influence on the reaction. As water is a medium of dissolution, ionization and transportation of CO₂, very low or very high water ratios will retard the reaction. High temperatures will improve the reaction velocity but do not improve the sequestration of CO₂ into the ash. The carbonation reaction is optimum at ambient temperatures and a water solids ratio of 0.3.

Mineralogical analysis of ash by XRD showed the disappearance of lime/portlandite and the formation of carbonate salts, such as calcite and vaterite upon carbonation. With ash from the Kirkles incinerator, hydration occurred as well as carbonation. The pH of naturally aged ashes collected from the Environment Agency is near 12, slightly lower than the fresh ashes, which were a pH of 12–12.5. The pH was reduced to between 7 and
9, depending on the reactivity of ash. Therefore, carbonation has a significant neutralizing effect on fly ash. The release of soluble salts, Cl and SO₄, were reduced by carbonation. The reaction also led to a significant reduction of lead mobility, although cadmium release was increased. It can be concluded that carbonation can reduce the hazardous nature of fly ash, and facilitate disposal and reuse.

References


Production of lightweight aggregate from industrial waste and carbon dioxide

Peter J. Gunning*, Colin D. Hills, Paula J. Carey

Centre for Contaminated Land Remediation, University of Greenwich, Chatham Maritime, United Kingdom

1. Introduction

New treatment methods that can convert waste into products reduce the amount of materials sent to landfill disposal and protect virgin raw materials for the future.

Annual waste production in the UK amounts to 335 million tonnes (DEFRA, 2007). Mining and quarrying wastes comprise 29%, whilst industrial processes are responsible for a further 13%. Landfilling has been widely used, but as space is due to run out in less than a decade. Despite increased recycling, large amounts of waste are not effectively reused. These include incineration residues which are often classified as hazardous on account of their alkalinity and heavy metal content. Typically, these ashes must be landfilled, and are subject to landfill taxation which is set to rise from £40 in 2009, up to £48 in 2010 (DEFRA, 2008).

Similarly, the need to improve carbon management has prompted industry to consider the mitigation of emissions using Carbon Capture and Storage schemes (CCS) at both the larger and smaller scale, but concerns have been raised over long term environmental impacts (IPCC, 2005). Finding a safe, permanent storage solution for carbon dioxide remains a major challenge. One option, particularly suited to smaller CO₂ point-source emissions involves the use of Accelerated Carbonation Technology (ACT) to bind carbon dioxide into solid carbonate using naturally reactive materials such as wastes arising from thermal processes.

Treatment by ACT can be applied to calcium and magnesium rich thermal residues, e.g. municipal and paper incineration ashes, wood ashes, pulverised fuel ashes, steel slags, etc. (Li et al., 2007; Fernández-Bertos et al., 2004; Johnson, 2000). Carbonation is achieved by exposing the waste to an elevated concentration of carbon dioxide gas in a controlled environment. The reaction takes place in the presence of moisture and carbon dioxide gas hydrates to form carbonic acid (1). In saturated conditions, carbonation is suppressed by the slower diffusion of carbon dioxide in water compared to air (Van Balen, 2005). The carbonation of hydrated Portland cement, converts Portlandite (2) and Calcium Silicate Hydrate (3) into carbonate. Unhydrated calcium oxide and silicates also form carbonates (Sulapha et al., 2003; Jiang et al., 2000). These phases are typically found in many thermal residues (Johnson, 2000) and can combine with significant amounts of carbon dioxide gas in a short timescale

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \tag{1}
\]

\[
\text{Ca(OH)}_2 + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2\text{H}_2\text{O} \tag{2}
\]

\[
3\text{CaO} \cdot 2\text{SiO}_2 \cdot 3\text{H}_2\text{O} + \text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + 2\text{SiO}_2 + 6\text{H}_2\text{O} \tag{3}
\]

Leachates generated from carbonated alkaline media have pH’s that are typically lowered by several units, and the formation carbonate results in an increase in density and mass. The hardened, densified product can have potential for re-use in engineering applications (Rendek et al., 2006; Johannesson and Utgenannt, 2001). Combining ACT with a method of making agglomerates allows waste to be reconstituted into a lightweight aggregate (Gunning et al., 2008; Padfield et al., 2004).
Agglomerating (pelletising) processes are used to increase the grain size of powders, by sticking particulates together with a liquid binder and mechanical agitation, such as by tumbling in a revolving drum. Particle bonding can only take place when the pores are almost totally saturated with liquid binder, to form liquid bridges between particles (Iveson and Litster, 1998). The permanent bonding of particles can be aided by the use of a chemical binder to improve handling and flow properties (Pietsch, 2003; Pottmann et al., 2000). The pelletising process is controlled by the physio-chemical properties of the input powder, the moisture content of the feed and process parameters such as rotation speed (Wang and Cameron, 2002; Iveson et al., 2001; Baykal and Doven, 2000).

The UK currently consumes around 280 million tonnes of aggregate annually, 25% of which is derived from secondary and recycled sources (WRAP, 2008). Virgin aggregates are subject to the Aggregate Levy, which is currently £2 per tonne produced. As recycled aggregates are exempt from this tax and natural stone resources are becoming scarce, there is increasing interest in the use of alternative materials (H.M. Revenue and Customs, 2009). Recycled aggregate can be sourced from spent construction materials including lightweight concrete (Tam et al., 2005). Aggregates with a bulk density below 1200 kg/m³ are classified as lightweight, which are commonly manufactured by pelletising and by sintering or firing (BS EN 13055: 2002). These energy intensive processes form low-density solid pellets by particle fusion and bloating the structure (Owens, 1993).

The objective of the present study was to examine the use of an accelerated carbonation process to reconstitute quarry waste and CO₂-reactive thermal residues into a material suitable for use as an aggregate, and the demonstration of the technology at pilot-scale.

### 2. Materials and methods

#### 2.1. Raw materials

The quarry fines were sourced from an active quarry producing around 1 million tonnes of crushed limestone annually. Processing the crushed rock generates 200,000 tonnes of waste in the form of poor quality sands and silts. A range of thermal residues were trialled as potential binders (Table 1). The wastes were sourced from facilities in the UK, and included biomass ash, cement bypass and kiln dusts (CBD and CKD), municipal waste incineration bottom and fly ashes (MSWI-BA and MSWI-FA) from two different incinerators, four paper ashes from separate mills, pulsed fuel ash (PFA), sewage sludge ash (SSA) and wood ash. The chemistry of the wastes were examined using X-ray fluorescence (Philips PW1400) (Table 2) and X-ray diffraction (Siemens D500) (Table 3).

#### 2.2. Accelerated carbonation

The reactivity of the wastes with carbon dioxide was measured in a pressurized reaction vessel. The oven-dried wastes were moistened with 10% water, and carbonated in a 100% carbon dioxide atmosphere held at 2 bar for 24 h. This process was repeated until the wastes were fully carbonated. Carbonate content was determined by thermogravimetry (Stanton–Redcroft STA-780 Series analyser). Complete carbonation was determined when the mass lost between 800 °C and 950 °C, remained constant (Heiri et al., 2001). The loss equates to the weight of carbon dioxide chemically combined in the material (according to 4)

\[
\text{CaCO}_3 \xrightarrow{\text{Heat}} \text{CaO} + \text{CO}_2
\]

### Table 1

<table>
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<td>Biomass ash</td>
<td>Fine ash residues from the incineration of plant matter from agricultural processes (Pitman, 2006)</td>
</tr>
<tr>
<td>Cement kiln/bypass dusts</td>
<td>Alkali-rich fine dusts removed from cement kiln exhaust gasses (Buchwald and Schulz, 2005)</td>
</tr>
<tr>
<td>Municipal solid waste incineration fly and bottom ashes</td>
<td>Produced from the incineration of domestic waste. Bottom ash is the coarse grained residue from the incinerator grate. Fly ash is fine grained airborne ash removed from the incinerator exhaust gasses (C.I.W.E.M., 2001; E.A., 2002)</td>
</tr>
<tr>
<td>Paper wastewater sludge incineration ash</td>
<td>Fine ash residue from incineration of paper making wastewater sludge containing residual fibres, and a mixture of fillers (kaolin, calcite) and chemicals (bleaching agents, de-inking compounds) (WRAP, 2007; Boni et al., 2004; DOE, 1996)</td>
</tr>
<tr>
<td>Pulverised fuel ash</td>
<td>Fine grained ash separated from the flue gases of coal-fired power stations (CIRIA, 1999; DOE, 1995a)</td>
</tr>
<tr>
<td>Sewage sludge ash</td>
<td>Fine ash generated by incinerating dewatered domestic wastewater sludge (DOE, 1995b)</td>
</tr>
<tr>
<td>Wood ash</td>
<td>Coarse ash derived from combined heat and power plants using sustainable wood sources (Pitman, 2006)</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
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<th>Al₂O₃</th>
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<th>Fe₂O₃</th>
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<th>MgO</th>
<th>Na₂O</th>
<th>P₂O₅</th>
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<td>0.1</td>
<td>19.8</td>
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</table>

OPC – Ordinary portland cement.
By measuring the carbon content of the untreated waste, the amount of CO₂ combined through accelerated carbonation can be calculated by difference.

2.3. Laboratory scale pelleting trials

Wastes having a significant reaction with CO₂ were defined as those that imbibed 5% or more of their dry weight of carbon dioxide. These materials had potential to self-cement and bind the non-reactive quarry fines into pellets. Quarry fines were mixed with these wastes, and with Portland cement as a reference binder, at 10, 20, 30, 40 and 50% by dry weight. Water was added and mixed into the material until it attained the consistency of firm dough. This material was pelleted in a drum pelletiser under a flow of carbon dioxide gas at ambient temperature and pressure. After pelleting, the aggregates were stored in a curing chamber under a flow of dry carbon dioxide for 72 h. The dry CO₂ helps to overcome the detrimental effect of the saturated pore network caused by agglomeration. Carbonation effectively stops when the material is saturated and only proceeds when it has dried sufficiently to allow CO₂ ingress (Cultrone et al., 2005).

European Standards tests for measuring compressive strength of lightweight aggregate are unsuitable for small batch sizes. An alternative method of measuring aggregate particle strength has been adopted here, the mean particle diameter was derived by taking three axial measurements, prior to crushing in a compression-test rig. The strength of carbonated pellets (in MPa) was calculated by difference.


c_\text{c} = \frac{F_c}{A_m} = \frac{F_c}{(\pi d_m^2/4)}

\text{(5)}

Where \( c_\text{c} \) is the compressive strength in megapascals, \( F_c \) is the fracture load in kilonewtons, \( A_m \) is the mean area of the pellet, and \( d_m \) is the mean diameter of the pellet.

Three commercial lightweight aggregates; Aardelite (auto-claved PFA), LECA (lightweight expanded clay aggregate), and Lytag (sintered PFA), were tested alongside the manufactured aggregates for comparison.

2.4. Pilot-scale trials

The mechanics of a laboratory experiment are rarely indicative of a full-scale industrial process (Schaafsma et al., 1998). To demonstrate the application of the process, a pilot-scale facility capable of producing 100 kg of LWA per hour was constructed (see Fig. 1). The quarry fines, thermal residue binder, and water were premixed in a 50 l pan mixer (Utranazz), conveyed to rotary carbonation reactor (see Fig. 2), and then discharged into a 1100 l curing chamber circulated with dehumidified CO₂ for seven days. Dehumidifying the gas allows the CO₂ to be circulated in a closed loop, without the wastage of venting to the atmosphere. For comparison, a sub-sample of the aggregate was allowed to carbonate through natural weathering for seven days.

Aggregate testing was conducted according to BS EN 1744 (chemical tests), BS EN 13055 (mechanical tests) and BS EN 1097 (physical tests). Concrete cubes were prepared and tested according to BS EN 12390 Parts 1–3. Mixes were prepared according to the recommended mix design for lightweight concrete incorporating Lytag aggregate (Lytag, 2004).

Pellets were impregnated with resin, sectioned, and polished for analysis by scanning electron microscopy (JEOL JSM5310LV fitted with an EDAX spectrometer). The accelerating voltage was 20 kV and the working distance was 15 mm.

3. Results and discussion

3.1. Waste characterisation

In accordance with the earlier work of Johnson (2000), carbon dioxide uptake can often be estimated with reference to the total oxide content for calcium, as determined by XRF analysis (see Fig. 3). Phase analysis by XRD (see Table 3) attributes high reactivity to the presence of lime (calcium oxide) and Portlandite (calcium hydroxide). The relationship shown is not linear, and this can be attributed to the presence of non-reactive calcium bearing phases. The presence of calcite (calcium carbonate) in the thermal wastes, suggests that atmospheric carbonation may have occurred at some point prior to the materials being dried, stored and analysed.

### Table 3

<table>
<thead>
<tr>
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<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

○ – Present in uncarbonated material, ● – Present in uncarbonated and carbonated material.

---

![Fig. 1. Schematic of the pilot-scale process.](image)
hydration. Hydration may occur as ashes are often conditioned with water to reduce dust during transportation.

Paper ashes were some of the most reactive wastes examined due to the addition of calcium carbonate in the papermaking process. Paper waste incineration results in the calcination of carbonate to calcium oxide. Depending upon the type and grade of paper being thermally treated, the lime content in the ash may vary widely (Walker, 2006).

Cement by-products often contain lime produced by calcination of the limestone feedstock. Cement Kiln Dusts exhibit lower reactivity as they are separated during the preheating stage of the cement production process, when the temperature is not sufficient to induce full calcination. Bypass dusts, tend to be more reactive as they have passed through the kiln firing stage (Sreekrishnavilasam et al., 2006; Singh et al., 1995).

The low reactivity wastes had little or no detectable levels of lime or Portlandite. MSWI composition is highly variable, depending upon the nature of the feed to the incinerator, and include metal, plastic and putrescible waste (Arickx et al., 2006; Bethanis et al., 2002). Biomass ash composition varies widely according to the nature of the plant matter being incinerated (Pitman, 2006) and XRD analyses revealed that the ash has a complex mineralogy, dominated by calcium and magnesium phosphates. Pulverised fuel ashes generated in the UK are derived from low calcium, superior coals, resulting in low reactivity class F ash, dominated by the aluminosilicate mineral mullite (DOE, 1995a). Calcium present in sewage sludge ash is predominantly bound in the non-reactive calcium phosphate mineral whitlockite.

3.2. Laboratory pelleting trials

Wastes reacting with greater than 5% w/w CO₂ were tested for binding quarry fines into pellets. Aggregates, typical of those formed when paper ash was used as a binder, are shown in Fig. 4 alongside the raw materials.

The binding strength of these materials was variable (see Fig. 5). Portland cement (used as the control binder) produced the strongest pellets. Cement kiln dust, wood ash and paper ash 3 produced pellets of comparable strength to proprietary lightweight expanded clay aggregate (LECA) and Aardelite, thus making them potentially suitable as binders.

Paper ash 3 showed binding potential, as previously demonstrated in an investigation of its hydraulic properties (Bai et al., 2003). The close proximity of large amounts of quarry fines to the site of the paper incinerator facilitated their choice as the two materials for inclusion in the pilot-scale production trials described below.

3.3. Pilot Scale Production

The testing of the pilot-scale carbonated pellets according to British Standards established their suitability for use as lightweight aggregates (see Table 4).

Commercial lightweight aggregates exhibit differing bulk densities and strengths. The properties required for LWA are generally end-use specific (BS EN 13055: 2002). LWA’s can be classified by their low bulk density and low strength, for ‘insulation’ applications, with medium density and strength for ‘blockwork’ production, and high density and strength for ‘structural’ use (IstructE, 1987).

By increasing the reactive binder content in the aggregates, and by accelerating the carbonation process, the compressive strengths obtained were increased. The resistance to freezing and thawing was also improved. Compressive strengths were typically higher than that of LECA and Aardelite (blockwork LWA), but lower than Lytag (structural LWA). Increasing the reactive ash content also re-
duced the apparent and bulk densities in the weathered pellets. However, accelerated carbonation resulted in an increase in density, due to carbonate formation. However, the ACT aggregates remained well below the specified bulk density limit for LWA of 1200 kg/m³ (BS EN 13055: 2002).

Elevated levels of sulphur and chloride can lead to the degradation of concrete. Sulphates react with hydrated Portland cement forming expansive minerals, which result in distortion and cracking. Chlorides cause the passive oxide layer on steel reinforcing bars to break down, leading to corrosion (Mehta and Monteiro, 2006). Levels of sulphur and chloride in the aggregate were below the published values for LECA (Maxit Group, 2008), and within the limits specified in British Standards. BS EN 13139: 2002 limits total sulphur to 1% by weight of the mortar product, whilst chloride content should not exceed 0.1% of dry mass of mortar (BS EN 998-2: 2003) or 0.2% of the mass of cement in concrete containing prestressed steel reinforcement (BS EN 206-1: 2000).

Accelerated curing of the aggregate enhanced carbonate formation (see Table 4), which is evident by scanning electron microscopy (see Fig. 6). Pellets allowed to naturally carbonate exhibit low-density structures, with discrete mineral grains of gehlenite (silicate containing aluminium and calcium) embedded in a fine, porous groundmass of calcium carbonate. Artificial carbonation caused a noticeable densification of the structure, as the fine groundmass was replaced by a solid mass of calcium carbonate. These structures may account for the enhanced strength and freeze–thaw durability of aggregates subjected to artificial carbonation.

Table 4
Pellet testing results.

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<th>30% ash</th>
<th>30% ash</th>
<th>50% ash</th>
<th>50% ash</th>
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<th>LECA</th>
<th>Aardelite</th>
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<td>ACT</td>
<td>Natural</td>
<td>ACT</td>
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<td>0.23</td>
<td>0.28</td>
<td>0.28</td>
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<td>ND</td>
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<td>820</td>
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<td>730</td>
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<td>720</td>
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<td>Strength (MPa)</td>
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<td>ND</td>
<td>&lt;0.04</td>
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</tr>
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</table>

* Values quoted by Maxit Group (2008), ND = not determined.
3.4. Aggregate end uses

Lightweight aggregates are utilised in a diverse range of applications including lightweight structural concretes, low-density construction blocks, engineering fill and horticultural growing mediums (Chandra and Berntsson, 2003).

The carbonated aggregates were incorporated into concrete cubes, intended for use as pre-cast lightweight concrete blocks. Concrete cubes made from the ACT aggregate and commercial LWA were tested for density and 28 day compressive strength (see Table 5). The cubes exhibited a satisfactory mode of fracture, as specified in BS EN 12390. All four exposed faces were cracked approximately equally, with minimal damage to the faces in contact with the compression machine platens. Fractures were propagated through the aggregate particles, rather than around the pellets, indicating good bonding with the cement paste.

British Standard (BS 8500-1:2006) allocates concrete to exposure classes based upon compressive strength. Exposure classes recommended the severity of the service environment to which the concrete is subjected. Although the strength of the 30% ash-bound aggregate fell short of the proprietary aggregate, it was still suitable for X0 applications, where concrete without reinforcement can be used in non-aggressive environments (BS 8500-1:2006). ACT aggregate bound with 50% ash was comparable to LECA concrete, and was suitable for use in XC1 applications, where concrete containing reinforcing is either maintained in a permanently wet or dry state, but not exposed to wetting and drying cycles. Therefore, carbonated aggregate blocks would be ideally suited for internal partition walls as an alternative to foamed concrete.

The accelerated carbonated aggregate product has been supplied for a pilot-scale green roof trial in the south-east of England. These vegetated roofs offer improved aesthetics and building insulation properties, and profound environmental benefits. In this application, a lightweight, absorbent medium is required to support plant growth without placing an excessive load on the roof structure (Johnston and Newton, 1997).

4. Conclusion

A range of combustion residues have been examined for use as CO$_2$-reactive binders in combination with quarry fines for the production of an accelerated carbonated aggregate. The carbonated aggregates produced had comparable properties to commercially available LWA’s.

The ACT aggregates produced in this study were composed of 100% waste and were formed by a cold-bonding process. This production route imbibes CO$_2$ gas unlike the fired or sintered aggregates available commercially.

A pilot-scale production plant was successfully used to produce carbonated aggregate for commercial trials and European Standard testing. It was established that the key properties of the carbonated aggregate were comparable to or better than equivalent proprietary LWA currently available in the UK.

Carbonated aggregates were tested for use in concrete blocks and as a horticultural growing medium in green roof systems. The technology described here is now being used to manufacture aggregate from other waste materials. Full-scale trials are planned to provide the foundation for the commercial production of accelerated carbonated aggregates for use in, for example lightweight block production.

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References


Commercial application of accelerated carbonation: Looking back at the first year

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Abstract
Carbon8 Systems is a university spin-out company developing and applying accelerated carbonation for the commercial production of aggregates from waste. Hazardous wastes can be converted into construction products that meet the regulatory requirements for ‘end of waste’ using carbonation. When the accelerated carbonation process is applied to municipal solid waste incineration (MSWI) air pollution control residues (APCr), the ash is solidified and stabilised in carbonate-cemented pellets. The pelletised products have mechanical and chemical properties that make them suitable for use in concrete blocks. In early 2012, following the success of a series of pilot and full-scale trials, a full scale carbonation plant was built and commissioned at Brandon in Suffolk, UK. This plant is the first of its kind in the world. The aggregate plant has now been operating for about a year and is producing a consistent product. Continued monitoring of the incoming APCr, and the outgoing aggregate product has dramatically increased the knowledge of processing this troublesome material. In addition to rigorous independent third party and in-house testing, the physical and chemical properties of the product are routinely examined to meet quality control criteria, and to ensure compliance with the ‘end-of-waste’ status approved by the UK Environment Agency.

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Introduction
In 2011, the UK had an incinerator capacity of 10.3 million tonnes, and it is projected this will increase considerably in the near future.1 There are strict controls on the emissions from incinerators as a result of the European Waste Incineration Directive. Lime, carbon, and sometimes ammonia, are usually added to flue stack of municipal incinerators to neutralise the pH and remove pollutants such as dioxins and volatile metals. The resulting Air Pollution Control Residue (APCr) is made up of reacted and un-reacted lime, carbon and particulates from the flue gas, and is collected in bag filters before the cleaned flue gas is released to the atmosphere.2,3,4 APCr generation is typically in the range of 2-6% of the total throughput of an incinerator.5

The majority of APCr is sent to either specialized hazardous landfill facilities or placed in underground storage. Facilities for hazardous waste disposal are tightly regulated, and few merchant sites exist in the UK that can receive APCr. The properties of APCr often exceed the acceptance criteria for hazardous landfill, and can only be disposed at
sites that have received a derogation permit. Hazardous waste is subject to the current active rate landfill tax of £64 per tonne, increasing to £72 in April 2013.6 Methods of treating APCr are under development, including washing the dusts with water to remove contaminants,7 and chemical treatments to induce dissolution, absorption, or the precipitation of contaminants. Thermal processes including vitrification into a stable glass-like material have been explored.4 A novel alternative is to solidify and stabilise the APCr using carbonation, in the process sequestrating this harmful greenhouse gas as a solid carbonate cement.8 The process enables the fine APCr to be formed into aggregates with properties that make them suitable for use as construction aggregates.

Carbon8 Systems and the related company Carbon8 Aggregates have been developing this process for commercial purposes, culminating in early 2012 with the construction of a full-scale commercial facility. The present work discusses lessons learned during commissioning and operation of this plant during the first year of operation.

Development of the Process

A decade of development of the carbonation process to convert APCr into aggregate has involved a number of stages, which are illustrated in figure 1.

The potential to rapidly harden pelleted wastes was observed during a series of laboratory and academic studies followed by pilot scale trials to assess the use of carbonation to promote the rate and extent of setting of stabilisation/solidification (s/s) treated soils.9 The production of carbonation-hardened agglomerates was progressed in two studies at the University of Greenwich.10,11 The potential to utilise a number of industrial residues to manufacture hardened pellets with mechanical properties suitable for use as a substitute for natural aggregate was then established.

In January 2010, a pilot scale trial at a hazardous waste landfill receiving APCr was undertaken to demonstrate the larger-scale application of the technology. Over a four week trial period, five tonnes of aggregate were produced, which was used in a small production run by a major UK construction block manufacturer.

The successful pilot-scale trial demonstrated that the carbonated APCr aggregate was fit for purpose and had commercial value. This was a key step to securing the initial investment required to set-up a temporary full-scale demonstration of the process, as described by Gunning et al. (2011).12 Construction of the demonstration plant took place in November 2010 in a warehouse on a site owned by a major UK commercial block manufacturer. The plant was operated for two months in the winter of 2010, and in excess of 200 tonnes of aggregate was manufactured. This was validated for use as an aggregate in concrete blocks through the manufacture of over 3000 blocks.
European waste legislation and its implementation in the UK has presented a number of challenges to the development of the carbonation process. At each stage of the scaling-up of the process, permission, in the form of a regulatory position statement, was required from the Environment Agency. The trials provided clear evidence of the quality of the aggregate that could be produced and through third party accredited testing of the physical and chemical properties of the product allowed a specification for the aggregate to be devised. The production of concrete blocks using the aggregate manufactured in the trials and the testing of these blocks to European Standard demonstrated that there was a clear end use for the material. By working closely with the Environment Agency, ‘End of Waste’ status for the aggregate was approved in August 2011.

The success of the full-scale demonstration led to the construction of the first commercial plant of its type in the world. Using the experience and know-how developed, this plant is capable of producing 36,000 tonnes of aggregate per year. Construction of the plant commenced in October 2011, and installation on site took place in January 2012.

**Commissioning the Plant**

The full-scale process for the production of APCr aggregates by the accelerated carbonation is shown in figure 2.

![Figure 2. Flowchart of the full-scale process](image)

APCr arrives at the site in 25 tonne powder tanker trucks and is transferred to two 85m$^3$ silos. The APCr passes through a treatment chamber, where initial carbonation of the APCr takes place, into a batch mixer where reagents are introduced as necessary, to produce a mixture that is then conveyed to pelletising units to be aggregated. Further addition of CO$_2$ induces chemical stabilisation and solidification of the aggregate. The aggregated product is then conveyed to one of five daily storage bays, and screened to produce the required grading for use in the on-site block making process operated by the UK’s largest independent concrete masonry manufacturer. The newly commissioned plant is shown in figure 3.

In February 2012, the plant was ready for initial trials to begin. Initial system checks and implementation of the computer control system was achieved whilst using kiln dried sand as an inert alternative to APCr that could be recycled through the process as necessary.

A quality assurance protocol was established to characterise the APCr arriving on site, in order to make fine adjustments and maintain optimum process efficiency. Similarly,
an equivalent protocol was developed for the aggregate placed in the storage bays, to ensure on-going compliance with the End of Waste specification. Through routine testing of the APCr and aggregate product, a robust understanding the relationship between the two has been developed.

The suitability of the APCr was judged upon handling characteristics including bulk density and moisture content, which determine the maximum capacity of the storage silos and identify any potential conveying issues. Compliance of the aggregate product is determined by physical properties (compressive strength, particle size, durability), and chemical characteristics (leaching of metals and anions).

The trials continued with the receipt of APCr from several different incinerators from around the UK. It was found that APCr varies significantly between different facilities, and that the process must be carefully tailored in each case.

With continued use of the plant, minor issues in the design, mostly relating to material flow through the process were identified. As a result, a phase of redesign and re-engineering was undertaken in the summer of 2012. The reconstructed plant resumed full operation in August of that year. The modifications made dramatically improved the running of the plant and reduced the amount of operator input, making a significant step towards a fully automated process.

Full-Scale Production

The plant has been fully operational since the re-engineering phase. Regular tanker deliveries were made to site as the level of production started to increase. With a consistent daily flow of aggregate, the product began to be incorporated into the standard concrete block range of Lignacite Ltd, the UK’s largest independent concrete block manufacturer.
APCr Properties
Routine monitoring of each tanker arriving at site has amassed a large database of APCr properties. Testing has included measuring physical and chemical properties, and carbon dioxide uptake.

Monitoring over a period of 220 days showed that the carbon-uptake of incoming ash did vary by several % w/w and that this information informed the aggregate-making process. The APCr testing programme revealed fluctuations in the reactivity of the APCr, and in key physical and chemical properties can result from changes in incinerator operating conditions, particularly after shutdowns for routine maintenance.

Aggregate Properties
Samples are collected daily from the aggregate product in the storage bays. In accordance with the end of waste approval, the product must be fit for purpose and also not pose a threat to the environment. Testing of aggregate compressive strength and loose bulk density are used as indicators of product quality. Figure 4 shows the results of monitoring over the same period as the APCr.

The specification in the End of Waste approval stipulates an average individual aggregate compressive strength of 0.1 megapascals, as determined by the method described in Gunning et al. (2009). European Standard imposes a maximum bulk density of 1200kg/m$^3$ for lightweight aggregate. Compressive strength of the aggregate is shown to consistently exceed the specification, whilst bulk density is
below the maximum specified. Fluctuations in the results are due to changes in the properties of the APCr, the mix formulation and processing parameters used.

**Block Properties**

In addition to the quality assurance testing of the incoming APCr and manufactured product, periodic testing of the blocks manufactured is also undertaken. The testing is carried out by an independent third party UKAS ISO 17025:2005 accredited laboratory. The most recent results are shown in table 1. For comparison, a set of blocks manufactured using the traditional formulation was tested alongside the APCr aggregate blocks.

The results show comparable properties between the two formulations in terms of strength (compressive and transverse failure), density, and geometry (flatness and parallelism). Drying shrinkage and moisture expansion in the blocks with APCr aggregate was less than those without APCr aggregate. Figure 5 shows a series of photographs depicting the block manufacturing process.

![Figure 5. Block manufacturing process (clockwise from top left – aggregate in storage bays; newly formed blocks; cured blocks on conveyor; stacked blocks (courtesy of Lignacite Ltd)](image-url)
Table 1. Physical properties of APCr aggregate and control concrete blocks (courtesy of Lignacite Ltd)

<table>
<thead>
<tr>
<th>Property</th>
<th>Without APCr Aggregate</th>
<th>With APCr Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1660</td>
<td>1730</td>
</tr>
<tr>
<td>Compressive Strength (MPa)</td>
<td>11.8</td>
<td>11.2</td>
</tr>
<tr>
<td>Transverse Failure Load (kN)</td>
<td>7.75</td>
<td>7.78</td>
</tr>
<tr>
<td>Flatness (mm)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Parallelism (mm)</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Drying Shrinkage (mm)</td>
<td>0.38</td>
<td>0.34</td>
</tr>
<tr>
<td>Moisture Expansion (mm)</td>
<td>0.13</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The Next Steps

A second plant is in the advanced design stage, and is scheduled for construction in the latter part of 2013. This plant will have a capacity three times that of the Brandon facility. A third plant is in early planning stages, with the intention to set up five plants in total over the next four years. The knowledge gained is also being applied to other waste streams in the UK and further afield.

Summary

The first year of operation of the commercial carbonation facility can be summarised:

- The world’s first commercial carbonated aggregate facility was installed in Brandon, UK in early 2012.
- Commissioning took place in February 2012, and identified a number of improvements required
- A phase of re-engineering the summer of 2012 enhanced the operation of the plant
- Since summer 2012, the plant has been fully operational, supplying carbonated aggregate to the UK’s largest independent concrete masonry manufacturer
- A quality assurance protocol was developed to monitor the APCr arriving on site and the product
- Continued monitoring of the APCr and aggregate product has identified trends in their physical and chemical properties and ensured compliance to the End of Waste License.
- A second plant is in the advanced stages of planning, with a further three plants due for construction over the next four years.
Acknowledgements

The authors would like to thank the other members of the Carbon8 team; Mark Orsbourn and Steven Greig of Carbon8 Aggregates Ltd. Their invaluable contribution to this endeavour is gratefully acknowledged. Also the immense support of Grundon Waste Management Ltd and Lignacite Ltd, in particular Allan Eastwood, has been invaluable. Many thanks also to Shane Pearson, manager of the Brandon processing facility, and his team.

References

ABSTRACT: Through the use of accelerated carbonation, Carbon8 Aggregates have developed an aggregate that captures more carbon dioxide than is used in its manufacture. The basic principles of the aggregates manufacture from the treatment of the residues from Energy from Waste plants are explained together with the rigorous quality assurance procedures that are in place at the company’s first site in Suffolk. The properties of the aggregate are described together with its current and potential uses.

Keywords: carbon dioxide, secondary aggregate, aggregate blocks, accelerated carbonation, end of waste,
INTRODUCTION

Carbon footprint of concrete
The use of concrete in construction, as the result of the manufacture of cement, the extraction of natural aggregate and transport of the raw materials is considered to have a relatively high carbon footprint. A figure of 79.7 kg/tonne is given as an indicator for CO₂ emissions from production of a standard concrete mix for 2013 [1]. Pressure is on architects, specifiers and designers to use materials with lower carbon footprints in order to win contracts. Therefore considerable effort has been put into reducing this figure, by using alternative fuels in the production of cement, use of cement replacements and the use of recycled aggregate in the concrete. Natural aggregate is generally considered to have a carbon footprint of 1.73 kg CO₂/tonne [2] at the quarry gate as a result of its extraction and processing. Recycled or secondary aggregate is slightly higher at 1.91 kg CO₂/tonne before it is transported. Transport of the aggregate adds considerably to the footprint, so that finding a local aggregate supply is one of the principal methods of reducing the embodied carbon of construction activities. [3] However, when combined with the carbon footprint of cement, it is difficult to envisage construction products that are carbon negative. The use of accelerated carbonation in the manufacture of a secondary aggregate, where carbon dioxide is permanently captured in the aggregate changes this position by producing an aggregate that is carbon negative. The aggregate is manufactured from Air Pollution Control residues (APCr) that are generated through the treatment of the flue gas from Energy from Waste plants (EfW).

Accelerated carbonation
Carbonation, in the concrete world, has generally been considered to be detrimental to concrete mainly because if it penetrates too far into reinforced concrete, the reduction in pH removes the protection for the steel and it corrodes. Early stage carbonation however, can produce a less permeable surface slowing down the penetration of other detrimental salts. These carbonation reactions involve reaction of the already hydrated cement phases and take place after the concrete has hardened. During accelerated carbonation, the green cement is exposed to CO₂ and carbonate phase form in preference to the hydrated phases and the carbonate acts as the binder rather than calcium silicate hydrates. The carbonation reaction is rapid, taking place in minutes rather than the hours involved in cement hydration, and the CO₂ is permanently captured in the product as carbonate.

Treatment of waste
Accelerated carbonation can be applied to cement or to a variety of other thermal residues or wastes such as steel slags, cement by-pass dusts or air pollution control residues (APCr). The later are generated through the injection of lime into the flue gas of Energy from Waste plants in order to meet the emission standards in the Waste Incineration Directive. The lime reacts with the acidic components in the gas and is collected in filter bags, alongside any flyash that has escaped the precipitators, and loaded into bags or tankers. Until recently, the majority of APCr is sent to either specialized hazardous landfill facilities, placed in underground storage or used as ‘engineering fill’ in salt mines at considerable cost, as a result of; gate fees, transport to the relative low number of facilities and, in the UK, high landfill tax. Principally because of the high chloride content of the APCr, it can only be disposed of to hazardous landfill as a result of a derogation of the waste acceptance criteria in the Landfill Directive. Not surprisingly, a number of methods of treating APCr are under development, including washing, [4] chemical treatments, and vitrification. [5]

The UK currently incinerates 10 percent of municipal waste, compared to the European average of 17.3 percent [6], and as landfill becomes an increasingly difficult waste management option through application of the Waste Hierarchy, more local authorities are turning to incineration to manage their residual waste. A number of EFW’s are currently being commissioned and several more are in planning such that there is potentially more than 250,000 tonnes of APCr that requires some sort of management option other than landfill.
As a result of the residual lime in the material and calcium silicates in the flyash, accelerated carbonation can be used to effectively solidify and stabilise APCr. Carbon8 Aggregates, have been operating commercially since 2012 and have developed the carbonation process such that the fine-grained dust is formed into pellets with properties that make them suitable for use as construction aggregates.
This paper describes the development of the process, and the future potential of the technology.

DEVELOPMENT OF THE AGGREGATE

The potential to rapidly harden pelletised materials was observed in 2000, during pilot scale trials to assess the use of carbonation to treat contaminated soils. [7] With a downturn in the remediation market, attention was turned to the treatment of industrial wastes and finding a use for the treated materials. The production of carbonation-hardened agglomerates from a number of industrial residues was progressed at the University of Greenwich, [8,9] and recognising the commercial potential Carbon8 Systems was formed in February 2006. In January 2010, a pilot scale trial at a hazardous waste landfill receiving APCr was undertaken to demonstrate the larger-scale application of the technology. This led to the formation of a new company, Carbon8 Aggregates dedicated to the treatment of APCr and the manufacture of a lightweight aggregate. A full-scale demonstration plant ran for eight weeks in November and December 2010. [10] The plant was used to manufacture in excess of
200 tonnes of aggregate, for use in validation trials as a gravel-replacement in concrete construction blocks, and to provide data for an application to the Environment Agency’s 'Modernising Waste Panel'. European waste legislation and its implementation in the UK has presented a number of challenges to the development of the carbonation process. At each stage of the scaling-up of the process, the support of the UK Environment Agency was required to allow waste to be received, treated and tested. The success of the pilot plant allowed Carbon8 Aggregates to secure the investment necessary to build a full scale commercial plant and a very productive partnership with Grundon Waste Management was initiated. In early 2012, a production facility capable of producing 18,000 tonnes of aggregate per year was built.

END OF WASTE PROCESS

As a result of the European Waste Directive, any substance or material that is discarded is declared a waste and has to be handled through the duty of care legislation. This means that the materials can only be transported by a registered carrier to a permitted site and even if it is recycled or treated it is still designated a waste until it has been agreed otherwise.

There are three routes to achieve 'End of Waste' in England and Wales, the first being via an Environment Agency/WRAP quality protocol. The second is compliance with End of Waste Regulations, which currently only cover iron, steel and aluminum scrap. The third is through an 'End of Waste' submission to the Environment Agency. These submissions are considered on a case-by-case basis by the Modernizing Waste Panel with reference to the Waste Framework Directive (2008/98/EC). Examination involves establishing that the product is distinct and marketable and can be used and stored with no worse environmental effects than the material it replaces.

To allow the manufactured aggregate to move freely after production and before Carbon8 Aggregates committed to the construction of the full-scale plant it was decided to submit an application to the modernising waste panel. One of the principle objectives of the full-scale pilot plant was to manufacture sufficient aggregate to permit the manufacture of concrete blocks for testing against EN 771, and provide data on the environmental performance of the aggregate. Two major concrete block manufacturers made blocks from the aggregate and demonstrated that the blocks met the standards with no detrimental effects. After nine months of deliberation, the 'End of Waste' application was approved in August 2011 allowing C8A to proceed to an application for an environmental permit and the design and build of the new plant at Brandon in Suffolk.

COMMISSIONING OF THE PLANT

The first commercial plant using accelerated carbonation was built at Brandon in Suffolk through a collaboration with Lignacite, a manufacturer of a wide range of both dense and medium dense concrete aggregate blocks. Initially, a single production line was installed. However, demand for the aggregate necessitated the construction of a second line in early 2014, increasing production to 50,000 tonne per year (see figure 1).

Figure 1. APCr processing plant (second phase)

The full-scale process for the production of APCr aggregates by the Carbon8 process is shown in figure 2.
APCr arrives at the site in 28 tonne powder tankers and is transferred to one of four 83m³ silos. The APCr passes through a pre-treatment chamber, where initial carbonation of the APCr takes place, into a batch mixer where reagents are introduced as necessary, to produce a mixture that is then conveyed to pelletising units to be aggregated. Further addition of CO₂ induces rapid hardening of the pelletised product. The product is then conveyed to storage bays, and screened to produce the required grading. The CO₂ used in the process at Brandon is delivered by tanker from the nearby sugar beet factory where it is captured and purified principally for use in food processing.

**FULL-SCALE PRODUCTION**

Carbon8 operates under a strict quality system in compliance with ISO14001, OHSAS18001 and ISO9001. Daily checks on the quality of the incoming APCr (including bulk density and carbon dioxide reactivity) and outgoing aggregate product (compressive strength, particle size) are carried out to ensure that it meets the required specification set out in the ‘End of Waste’ documentation. APCr is received from four EFWs and aggregate is being regularly supplied to two local block manufacturers.

**AGGREGATE PROPERTIES AND APPLICATIONS**

C8Aggregate has a density of less than 1200 kg/m³ (Table 1) and is therefore classified as lightweight and should be compared with other similar aggregates, such as Leca or Lytag (Table 2). C8Aggregate is grey sub-rounded, homogeneous, and with a rough surface, that can be used for a variety of applications and is tested in accordance with EN 13055-1 (2002). C8Aggregate has good thermal properties, with a thermal conductivity between that of an Expanded Clay aggregate and flint gravel. (Figure 3)

**Table 1: Table of properties**

<table>
<thead>
<tr>
<th>Particle size</th>
<th>0 - 15 mm</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry loose bulk density</td>
<td>Minimum</td>
<td>950 kg/m³ EN 1097</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>1100 kg/m³ EN 1097</td>
</tr>
<tr>
<td>Particle density</td>
<td>Oven dried</td>
<td>1.94 kg/m³ EN 1097</td>
</tr>
<tr>
<td>Crushing Resistance</td>
<td>Typical</td>
<td>6.6 N/mm² EN 13055</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>5.2 N/mm² EN 13055</td>
</tr>
<tr>
<td>Moisture content as delivered</td>
<td>Typical</td>
<td>8 %</td>
</tr>
<tr>
<td>Water absorption</td>
<td>18.8 %</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Water soluble chloride</td>
<td>4.2 %</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Water soluble sulfate</td>
<td>0.1 %</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Total sulfate (as SO₃)</td>
<td>1.78 %</td>
<td>EN 1744</td>
</tr>
<tr>
<td>Resistance to Attrition (Los Angeles)</td>
<td>39 %</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Magnesium sulphate soundness</td>
<td>30.1 %</td>
<td>EN 1097</td>
</tr>
<tr>
<td>Drying shrinkage</td>
<td>0.021 %</td>
<td>EN 1367</td>
</tr>
</tbody>
</table>
**Table 2:** Properties of C8Aggregate compared with two other lightweight manufactured aggregates

<table>
<thead>
<tr>
<th></th>
<th>Oven dried density kg/m³</th>
<th>Water Absorption %</th>
<th>Mean crushing resistance N/mm²</th>
<th>Water Soluble Chloride %</th>
<th>Acid soluble Sulfate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C8Aggregate</td>
<td>1020</td>
<td>18.8</td>
<td>6.6</td>
<td>4.2</td>
<td>0.24</td>
</tr>
<tr>
<td>Lytag</td>
<td>750</td>
<td>27.1</td>
<td>6.5</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Leca</td>
<td>350</td>
<td>30</td>
<td>1.1</td>
<td>&lt;0.02</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

**Figure 3:** Thermal conductivity ($\lambda$) of C8Aggregate compared to Expanded clay (EC) and Flint (O)

In contrast to expanded clay aggregate or other sintered products, C8Aggregate is manufactured at ambient temperatures and pressures and therefore has a low carbon footprint. It can be shown to be carbon negative (up to ~44 kg CO₂/t depending on the source of the APCr) as the amount of carbon dioxide permanently captured in the carbonation process is greater than that generated by the power requirements of the plant or inherent in the other ingredients. When used in Lignacite's blocks, the blocks perform in EN 771-3 tests as well as those without the C8Aggregate and the blocks can be demonstrated to be carbon negative (~5 to -14 kg/t). As a result Lignacite launched their ‘Carbonbuster’ block in July 2012 as the world’s first carbon negative concrete block.

C8Aggregate can be supplied in particle gradings between 50mm and sub-1mm. The aggregate has been trialled and is suitable for use in a range of products, including concrete construction blocks, concrete, and floor screeds (see figure 4).
Concrete construction blocks

Blocks made with C8Aggregate can fully comply with European Standard BS EN 771-3. Lignacite Ltd is amongst several manufacturers utilising C8Aggregate in concrete block production, and is the UK’s largest independent producer. Their ‘Carbon Buster’ block is certified as carbon negative up to -14kg/tonne, and contains up to 50% recycled content. Quality control testing has been carried out by an independent third party UKAS ISO 17025:2005 accredited laboratory. The most recent results are shown in table 3. For comparison, a set of blocks manufactured using the traditional formulation was tested alongside the Carbon Buster blocks. The results show comparable properties between the two formulations in terms of strength (compressive and transverse failure) and density.

Table 3. Physical properties of concrete blocks with and without C8Aggregate

<table>
<thead>
<tr>
<th>Property</th>
<th>Without C8Aggregate</th>
<th>With C8Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1660</td>
<td>1730</td>
</tr>
<tr>
<td>Compressive Strength (MPa)</td>
<td>11.8</td>
<td>11.2</td>
</tr>
<tr>
<td>Transverse Failure Load (kN)</td>
<td>7.75</td>
<td>7.78</td>
</tr>
</tbody>
</table>

Ready-mixed concrete

C8Aggregate is suitable for use as partial or full replacement of natural aggregates in ready-mix concrete. Figure 4 shows the thermal conductivity of concrete made with C8Aggregate compared with concrete made from flint gravel or expanded clay. The C8Aggregate concrete also has a lower specific heat capacity and thermal diffusivity than concrete with flint aggregate.
**No Fines Floor Screed**

C8Aggregate is ideal for no-fines base course in a lightweight screed system. Lightweight screed omits the fine aggregate normally used in concrete to produce a highly-porous and low density structure which has enhanced thermal and acoustic properties. C8Aggregate is shown in figure 3 as part of a screed system comprising a 75mm layer of no-fines concrete with a 25mm mortar cap. Strength data is presented in figure 5, with accompanying density data in figure 6.

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**Figure 4.** Thermal conductivity of concrete made with C8Aggregate (C8), expanded Clay (EC) or Flint (O)

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**Figure 5.** Strength of no-fines concrete containing C8Aggregate

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**Figure 6.** Density of no-fines concrete containing C8Aggregate
SUMMARY

Carbon8 has developed and operates a commercial process for the recycling of municipal incinerator air pollution control residue as construction aggregate:

- The aggregate product has been rigorously tested and received ‘end-of-waste’ classification by the UK Environment Agency
- The world’s first commercial carbonated aggregate facility was installed in Brandon, UK in early 2012
- C8Agggregate can be used as a direct replacement for natural gravel, and is certified carbon negative
- Product manufacture is according to a quality system in compliance with ISO14001, OHSAS18001 and ISO9001 to ensure compliance to the End of Waste License, and
- A second plant is under construction, with a third plant in the advanced stages of planning, with a further two plants due for construction over the next two years.

REFERENCES

2. WRAP ESRA Tool
‘The Carbon Buster’ is made up of more than 50% recycled material.

This includes the Carbon8 pellets which are produced by combining CO₂, sand, cement and water. The result is a unique aggregate that, when incorporated into Lignacite’s products, creates the first ever carbon negative building block.

- Incorporates recycled and carbonated aggregates from by-products
- Captures more CO₂ than is emitted during its manufacture
- Invented and made in Britain
- Key to meeting zero carbon home targets
- Suitable for facing and general purpose applications.

Reducing Embodied Carbon

Clients and specifiers are increasingly looking at the embodied carbon of materials that are used and their end of life carbon impacts. Current Part L energy efficiency standards do not consider this aspect but as buildings continue to become more energy efficient so the relative importance of whole life carbon emissions in buildings increases.

The Carbon Buster block has been developed with low carbon impact as its main benefit. This is achieved not only by using carefully selected raw materials, but by incorporating lightweight aggregates, including graded wood particles, that sequent a large amount of carbon dioxide (CO₂). Carbon sequestration is the process of capturing and storing of atmospheric carbon dioxide. In this context Carbon Buster can be described as a carbon reservoir.

Carbon Buster’s carefully selected combination of raw materials result in a walling product that is carbon neutral and therefore can be specified for building projects that aim to achieve a low carbon design.

Carbon Methodology and Authority

The methodology used to determine the carbon footprint of Carbon Buster as well as other products, is PAS 2050:2011 ‘Specification for the assessment of the life cycle greenhouse gas emissions of goods and services’. The Study to assess carbon footprinting values was conducted by the School of Science, University of Greenwich Comparison of Building Materials. The performance of Carbon Buster can be compared to other building materials by reference to Table A opposite. Embodied energy for comparison purposes is based on ‘Cradle-to-Grave’ but excluding transport from factory gate to the construction site.

Table - Embodied CO₂ for Carbon Buster and other building materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Embodied CO₂ (kg/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete - typical</td>
<td>130</td>
</tr>
<tr>
<td>Common Bricks</td>
<td>220</td>
</tr>
<tr>
<td>Carbon Buster 3.6N/mm²</td>
<td>-14</td>
</tr>
<tr>
<td>Carbon Buster 7.3N/mm²</td>
<td>-3</td>
</tr>
</tbody>
</table>

Note: Data for generic materials taken from the ‘Inventory of Carbon and Energy (ICE)’, University of Bath.
**General Properties - Table 1**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Size</td>
<td>440mm x 215mm</td>
</tr>
<tr>
<td>Dimensional Tolerances</td>
<td>Category: D1</td>
</tr>
<tr>
<td>Mean Unit Strength</td>
<td>3.6N/mm²</td>
</tr>
<tr>
<td></td>
<td>7.3N/mm²</td>
</tr>
<tr>
<td>Net Dry Density</td>
<td>1450kg/m³</td>
</tr>
<tr>
<td>Thermal Conductivity @ 3% moisture content</td>
<td>0.79 W/mK</td>
</tr>
<tr>
<td>Moisture Movement</td>
<td>&lt;0.8mm/m</td>
</tr>
<tr>
<td>Reaction to Fire</td>
<td>Class A1</td>
</tr>
<tr>
<td>Air Tightness</td>
<td>100mm solid (bare) - 4.17 m³/hr/m²</td>
</tr>
<tr>
<td></td>
<td>140mm SP (bare) - 4.62 m³/hr/m²</td>
</tr>
<tr>
<td>Configuration</td>
<td>Solid Blocks: Group 1</td>
</tr>
</tbody>
</table>

- For use internally and externally above and below ground
- High levels of air tightness, sound insulation and fire resistance.

Carbon Buster block is available in Standard grade, for locations where the surface will not be visible e.g. plastered.

**Appearance**

Carbon Buster blocks are medium grey in colour with an open textured surface.

**Standards**

Carbon Buster blocks are BSI Kitemarked approved to BS EN 771-3. They are Category 1 masonry units manufactured under a BSI certified Quality System complying with BS EN 9001.

**Applications**

Carbon Buster blocks are suitable for use in commercial and housing projects. Carbon Buster blocks can be used in the following locations:

- The inner and outer leaves of external cavity walls
- Internal walls including fire break walls
- Separating walls including those conforming to Robust Detail specifications
- External and internal walls below ground (3.6N/mm² blocks can be used in both inner leaf and internal walls; 7.3/mm² blocks to other locations)

**Sound Insulation**

Carbon Buster blockwork provides excellent levels of sound insulation between buildings and adjoining rooms. It can be used in cavity party wall constructions in dwellings, satisfying the specifications for lightweight blockwork in accordance with Approved Document E to the Building Regulations. It can also be used to construct party walls meeting Robust Detail specifications eg. Robust Details E-WM-2, 4, 8, 11,14, 17, 19, 20, 21 and 22.
**Sustainability**

Responsible sourcing - Lignacite Ltd operates its manufacturing plants to a BSI certified Environmental Management System (EMS) complying with ISO14001. Lignacite Ltd. complies with the requirements of BES 6001 - Framework Standard for the Responsible Sourcing of Construction Products, Certificate No: BES 580823. This independently confirmed Responsible Sourcing Certification provides re-assurance to our customers that they are procuring products responsibly and sustainably. Credits can also be gained under environment assessment schemes such as BREEAM and the Code for Sustainable Homes.

Environmental ratings - Summary green guide ratings applicable to Lignacite blocks can be obtained from the BRE Green Guide to Specific Guide to Specification.

**Design**

The design of walls incorporating the Carbon Buster block should be in accordance with relevant design standards including BS 8103 Part 2 and BS EN 1996-1-1 and requirements of the Building Regulations.

**Surface Finish Recommendations**

**Drylining** - Application to be as manufacturer’s recommendations.

**Dense Plaster** - Apply either 1:1:6 cement:lime:sand or 1:4 ½ Masonry cement:sand or 1:5 ½ cement:sand and plasticiser. Alternatively: Thistle Bonding or Thistle Hardwall or Knauf Ultimate backing plaster.

**Finishing Coats** - Thistle plaster finish or Thistle multi-finish or Knauf Multi cover.

**External Rendering** - Rendering to be in accordance with BS EN 13914-1. Avoid over strong mixes. Ensure the first coat of render is applied to a greater thickness than successive coats. An initial spatterdash coat is advisable, consisting of 1 part cement, 1 part sand, gauged with a proprietary bonding agent (SBR). Builders considering the use of proprietary single coat render systems must exercise caution to accurately adhere to the render manufacturers’ design and specification guides. Furthermore, during application, strictly adhere to the specific and expansive application instructions, paying particular attention to prevailing weather conditions applied thereto. PLEASE NOTE that traditional rendering applications are not so seasonally and conditionally demanding.

**Movement Control**

Movement joints should be considered in accordance with PD 6697 at approximately 6.0 metre spacings. In areas of concentrated stress, such as those above and below openings, consideration should be given to the use of bed joint masonry reinforcement.

**Mortar**

The mortar type for work above ground level should be designation (iii) / Compressive Class M4. Stronger mixes may be used only with the permission of the designer. Stronger mixes may also be required for work below ground in accordance with PP 6697.

**Block Weights - Table 2**

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Form</th>
<th>Unit Weight (kg)</th>
<th>Laid Weight (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Solid</td>
<td></td>
<td>14.9</td>
<td>159</td>
</tr>
<tr>
<td>140 Solid</td>
<td></td>
<td>19.2</td>
<td>206</td>
</tr>
</tbody>
</table>

Note: Weights are based on 3% moisture content by weight.

**Sound Reduction - Table 4**

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Form</th>
<th>L/tweight Plaster</th>
<th>Dry Lined</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Solid</td>
<td></td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>140 Solid</td>
<td></td>
<td>51</td>
<td>51</td>
</tr>
</tbody>
</table>

Note: 1. The above values are based on technical assessments and tests to BS EN ISO 140-3.
2. Surface finishes are assumed to be applied to both wall faces.

**Thermal Resistances - Table 3**

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Form</th>
<th>3% m/c</th>
<th>5% m/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Solid</td>
<td></td>
<td>0.111</td>
<td>0.103</td>
</tr>
<tr>
<td>140 Solid</td>
<td></td>
<td>0.177</td>
<td>0.167</td>
</tr>
</tbody>
</table>

Note: 3% moisture content (m/c) should be used for protected locations such as the inner leaf, and 5% for exposed locations such as the outer leaf when rendered.

**Fire Resistances - Table 5**

<table>
<thead>
<tr>
<th>Width (mm)</th>
<th>Form</th>
<th>Loadbearing</th>
<th>Non Loadbearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 Solid</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>140 Solid</td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: The above values are for single leaf walls with no finish.

**Accreditations**

Brandon: 01842 810678 | Nazeing: 01992 464441 | info@lignacite.co.uk | www.lignacite.co.uk
Manufacturer Statement on Experience, Quantity & Demonstration

Summary

The following information is given to CEN TC154 to assist in its consideration re the application for inclusion of a new source material in EN 13055:(2014) Annex A for the inclusion of a new source material - Aggregate Manufactured using Accelerated Carbonation Technology (ACT) from APCr or Fly Ash from Energy from Waste

History

The use of Accelerated Carbonation Technology for the treatment of Thermal Residues and the manufacture of a sustainable carbon negative aggregate has been developed by Carbon8 following 15 years of award winning research undertaken at Imperial College, London and The University of Greenwich.

Pioneered by leading academics in their field, Professor Colin Hills and Dr Paula Carey, the business is currently one of only a few companies in the UK to hold an Environment Agency ‘End of Waste’ agreement, classifying the finished aggregate as a ‘product’.

The aggregate manufacturing process uses a patented process – Accelerated Carbonation Technology (ACT) – where waste carbon dioxide gas is used as a resource to treat a wide range of thermal wastes.

Many thermal wastes react naturally with carbon dioxide, and if the reaction conditions are carefully controlled, this natural reaction can be accelerated, taking place in minutes rather than months or years and resulting in the formation of artificial limestone.

During the process, significant volumes of carbon dioxide are permanently captured as stable carbonates. The growth of the carbonates chemically stabilises and encapsulates contaminants reducing the pH of the system and locking up heavy metals.

In the Carbon8 manufacturing process, the carbonated material is blended with binders and fillers and then pelletised with further carbon dioxide to form a rounded aggregate (C8A) that has a number of applications in construction.

The resulting aggregate has captured more carbon dioxide than is associated with the energy required in its manufacture resulting in the world’s first carbon negative aggregate.

Manufacture is carried out under strict quality systems, to ensure the aggregate complies with the product specification developed by Carbon8 Aggregates. The operating business has certification to ISO 9001, ISO14001 & OHSAS 18001.
All of our products can currently be supplied in compliance with BS EN 13055-1:2002 Lightweight aggregates – Part 1: Lightweight aggregates for concrete, mortar and grout and BS EN 13055-2:2004 Lightweight aggregates – Part 2: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications.

The product has received industrial recognition as the National Recycled Product of the year 2013, and through the CIWM innovative practice award (2013) and the MPA/British Precast sustainability award 2014.

**Quantity**

Since commissioning of the first industrial scale plant in early 2012, over 150,000 tonnes of aggregate have been manufactured and used mainly in the manufacture of concrete masonry blocks, and precast concrete units. There is also experience of use in un-bound applications although testing and compliance work in this area continues. Laboratory work is in progress to understand the use of the aggregate in bituminous mixtures.

It is expected that by the close of 2015 production capacity will increase to over 170,000 tonnes per year, with further increases in 2016 to approximately 250,000t.

**Demonstration**

Practical demonstration of the aggregate are given in technical data sheets, C8A – Block Mix, C8A – PC, C8A- RM & C8A-Screed, these sheets are available for download at [www.c8a.co.uk](http://www.c8a.co.uk)