

CARBON NEGATIVE: FIRST COMMERCIAL APPLICATION OF ACCELERATED CARBONATION TECHNOLOGY

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Abstract

Carbon dioxide gas can be used as a resource to rapidly harden cementitious materials and manage the risks associated with hazardous waste and contaminated soil. The process is known as Accelerated Carbonation Technology or ACT. Carbon dioxide primarily combines with calcium and/or magnesium minerals present in many industrial thermal residues to form carbonates; this reaction can also be promoted by the addition of, for example, Portland cement.

Carbon8 Systems Ltd. was formed in 2006 as spinout-company of the University of Greenwich to commercialise ACT. Carbon8 has applied ACT to hazardous wastes in the production of non-hazardous construction products.

By using the Carbon8 process, industrial thermal residues are solidified and stabilised in a hardened pellet form. The pelleted product is a direct substitute for natural aggregate, and can be used in the production of concrete construction blocks.

From 2009 to 2012, a series of pilot and full-scale demonstrations of the technology were carried out. The aggregates produced were rigorously tested and given 'end-of-waste' designation by the Environment Agency.

In early 2012, a bespoke commercial plant was commissioned at Brandon in Suffolk, UK, operated by Carbon8 Aggregates Ltd. This plant, the first of its kind anywhere in the world, produced 24,000 tonnes of aggregate from municipal solid waste incineration (MSWI) air pollution control residues (APCr) in its first year.

In 2014, a second production line was added to the Brandon facility, increasing its capacity to 50,000 tonnes per year. The aggregate is supplied to Lignacite, the UK's largest independent concrete block manufacturer, and other companies.

The ACT-produced aggregate is carbon negative as it contains more imbibed carbon than is generated by its production. Consequently, the concrete construction blocks produced by Lignacite are also carbon negative, and are marketed under the name: 'Carbon Buster'.

Plans are at an advanced stage for the construction of a second and third production facility in the UK. These are scheduled to be operational by mid-2015 and will increase aggregate production to 200,000 tonnes per year.

The present work discusses the development of the Carbon8 process and describes the commercial application of accelerated carbonation technology for the production of sustainable carbon-negative construction materials.

Introduction

Carbonation is a naturally occurring process, which can be accelerated by exposing reactive materials to a higher concentration of carbon dioxide gas than that available from the atmosphere. Carbon dioxide primarily combines with calcium and magnesium phases to form calcium carbonate (CaCO_3). Calcium carbonate is more voluminous than the reactant minerals and infills pore space, which facilitates the retention of contaminants.¹⁻³ By exploiting this mechanism, fine grained powders can be cemented together by the reaction with carbon dioxide to form aggregates with re-use potential.⁴

Many wastes have been found to be susceptible to carbonation; primarily those derived from industrial thermal processes, including paper ashes, biomass ashes, pulverised fuel ashes, steel slags and incineration residues.⁵⁻⁸

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 hazardous waste into aggregate has involved a number of stages, which are illustrated in figure 1.



Figure 1. Stages in the development of the process

Laboratory R&D

The potential to rapidly harden pelleted wastes was observed during 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 During mixing the soil with reagent binder and carbon dioxide, hardened nodules formed, which were persistent in the disposed treated soil. The production of carbonation-hardened agglomerates was progressed in laboratory research 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 (see table 1).

Table 1: Wastes successfully valorised as artificial aggregate by accelerated carbonation

Waste	Description
Biomass ash	Ash from burning biomass residues (including wood ashes)
Cement Kiln Dust	By-product from Portland cement manufacture
Clinical Ash	Ash from the incineration of hazardous medical waste
MSWI Ash	Municipal Waste Incineration (MSWI) residues, including coarse bottom ashes (-BA), fly ashes (-FA) and air pollution control residues (-APCr)
Paper Ash	Ash from incineration of paper recycling wastewater sludge
Pulverised Fuel Ash (PFA)	Ash from the combustion of coal for power generation
Quarry Fines	Sands, sludges, dusts etc. produced by extracting and processing rock
Sewage Sludge Ash (SSA):	Ash from incineration of wastewater treatment sludge

Steel Slag	metallic waste from steel manufacture
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Pilot Scale Trials

In January 2010, a pilot scale trial was undertaken using APCr, the hazardous alkaline residue from municipal incinerator flue gas cleaning systems, to demonstrate the larger-scale application of the technology. The production process devised incorporated a number of stages, which are shown in figure 2. 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 (see figure 3).

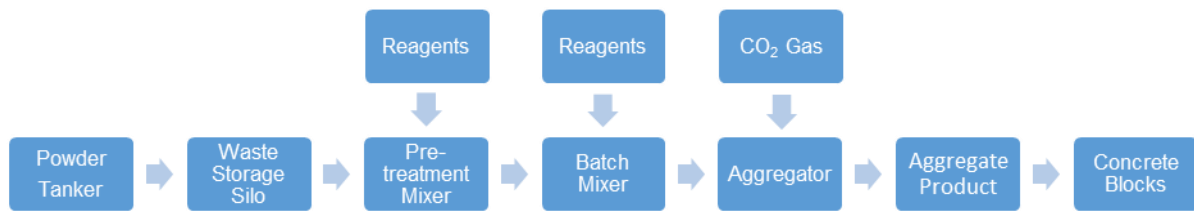


Figure 2: Flowchart of production process



Figure 3: Pilot scale trial; pre-treatment mixer (left), tonne bags of carbonated aggregate (right)

Full Scale Demonstration

The successful pilot-scale trial demonstrated that the carbonated APCr aggregate was fit for purpose and had commercial value. Construction of the demonstration plant took place in November 2010 (see figure 4). 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.¹²

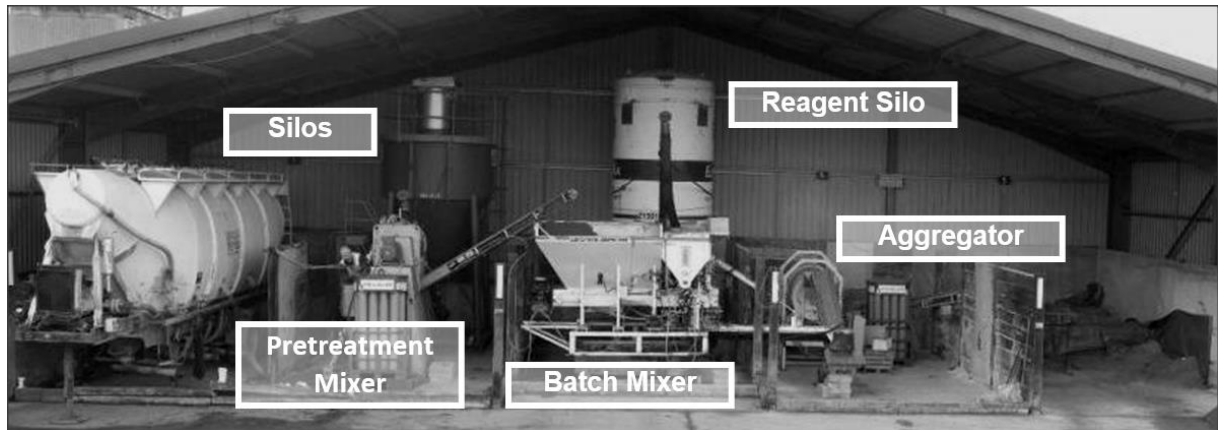


Figure 4: Full scale demonstration process setup

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.

Development and Construction of the Full Scale Plant

The success of the full-scale demonstration led to the construction of the first commercial plant of its type in the world. Construction of the plant commenced in October 2011, and installation on site took place in January 2012. The plant layout resembled that established with the demonstration facility. Silos store the APCr and any required reagents. A refrigerated tank stores liquid CO₂ for use in the carbonation process. This CO₂ has been captured from the gaseous waste emissions of an industrial process and is thus, not released into the atmosphere.¹³ The completed facility is shown in figure 5.



Figure 5. The newly commissioned plant

The APCr is pre-treated and aggregated, and transferred to storage bays which each hold one day's production. Daily checks on the quality of the incoming APCr and outgoing aggregate product are carried out to ensure that it meets the required specification set out in the 'End of Waste' documentation.

The plant currently receives APCr from two incinerators located in the south of England and the manufactured aggregate is used in the production of medium-weight concrete blocks.

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.

Commercial Operation of the Full Scale Plant

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 6 shows the results of monitoring the properties of the aggregate over a period of 300 days.

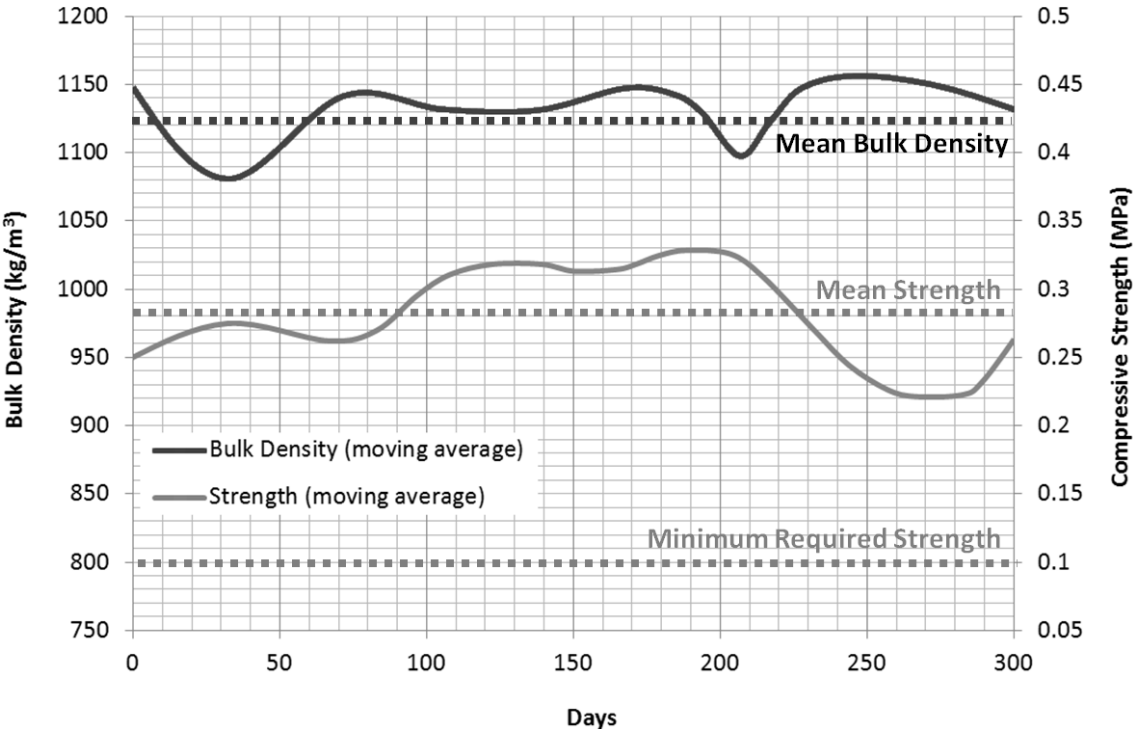


Figure 6. Properties of the aggregate product

The specification in the End of Waste approval stipulates an average individual aggregate compressive strength of 0.1 MPa. European Standard imposes a maximum bulk density of 1200kg/m³ 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.

In addition to the quality assurance testing of the incoming APCr and manufactured product, routine testing of the blocks manufactured is also undertaken. The testing is carried out by an independent third party UKAS ISO 17025:2005 accredited laboratory. Table 2 shows the properties of blocks containing carbonated aggregate compared a set of blocks manufactured using the traditional formulation.

Table 2. Physical properties of APCr aggregate and control concrete blocks (courtesy of Lignacite Ltd)

Property	Without APCr Aggregate	With APCr Aggregate
Density (kg/m ³)	1660	1730
Compressive Strength (MPa)	11.8	11.2
Transverse Failure Load (kN)	7.75	7.78
Flatness (mm)	0.0	0.0
Parallelism (mm)	1.2	1.0
Drying Shrinkage (mm)	0.38	0.34
Moisture Expansion (mm)	0.13	0.11

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.

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