



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

WRT 177 / WR0115

Industry Sector Study:

Manufactured Aggregates



October 2007

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

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1 Scope

This report describes the results of an assessment of the role of alternative raw materials derived from mineral 'wastes' and by-products in the production of manufactured aggregates. The report reviews the manufacturing processes and markets for the aggregates, sustainability issues in the sector, and the utilisation of alternative raw materials. These alternative raw materials may either be added to 'traditional' materials used to produce manufactured aggregates or used on their own, or blended, to provide the feedstock for manufactured aggregate production. It also describes the key properties that are required of these alternative raw materials, reviews current waste exchange mechanisms and provides a characterisation framework. It also mentions relevant standards and quality protocols to encourage wider utilisation of alternative mineral materials.

In terms of definitions used in this sector review the term manufactured aggregate will be used for mineral (and occasionally other) based materials that are processed using thermal or chemical means to produce a granular material suitable for incorporation into a variety of construction scenarios. Such incorporation may either be as a replacement for traditional aggregates or as a material that provides specific properties that natural materials cannot provide or where such materials are in short supply or inaccessible. In the majority of cases production is from a fine grained material (powder, dust, clay) so some form of agglomeration is needed to produce a granular material suitable for use as an aggregate. Usually the aggregate material is used at between 4 - 20 mm.

2 Manufacture Aggregates in the U.K.

Manufactured aggregates play only a very small role in the supply of aggregates to the UK market. Total aggregate supply for the UK (excluding N. Ireland) for 2006 is 274 million tonnes (Mt). Of this demand the majority is supplied by natural materials from crushed rock and land-won or marine dredged sand and gravel (204 Mt). In recent years the volume of recycled material from processed construction and demolition waste or hard granular materials from other industries such as steel production, has increased steadily to 27 percent, or some 74 Mt [QPA 2006], see Figure 1. However, the use of manufactured aggregate is much smaller and is currently less than a million tonnes per annum. This is both produced nationally and imported from continental Europe. It is almost entirely consists of lightweight aggregate (less than 1000kg/m³) and is predominantly an expanded (or bloated) clay aggregate, aggregate made from pulverised fuel ash (PFA) from coal fired power stations and naturally occurring pumice.

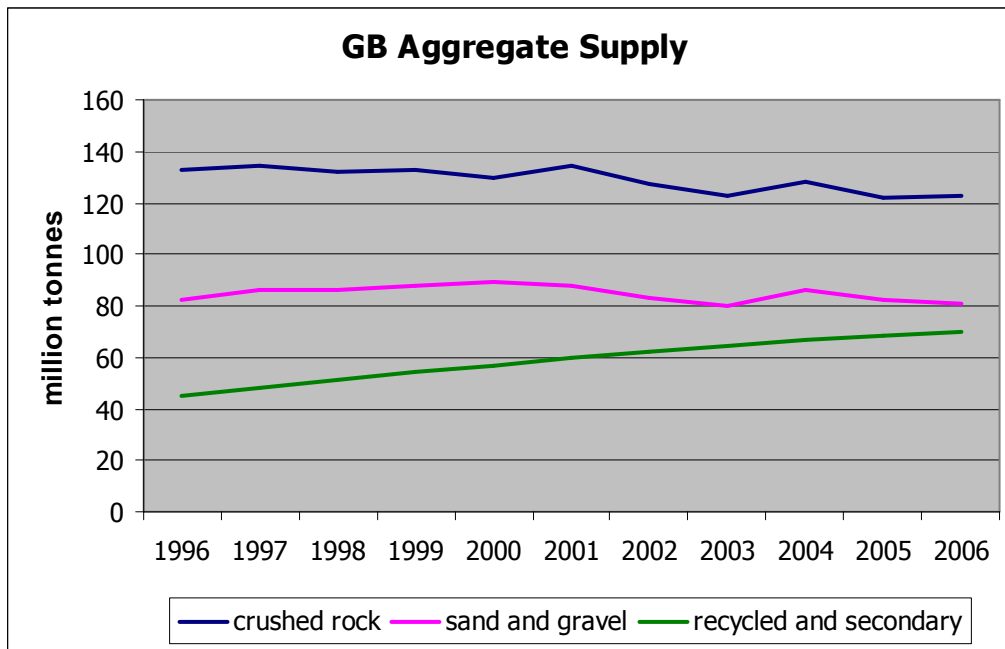


Figure 1: UK (excluding Northern Ireland) Aggregate Supply - source Quarry Products Association

Current UK production of lightweight aggregate is entirely expanded clay and amounts to ~ 150,000 tonnes per annum. Imports of expanded clay and PFA derived aggregates amounts to ~ 50,000 - 150,000 tonnes per annum [Pers. Comm. 1]. Pumice imports can amount to 100,000 tonnes per annum [Pers. Comm. 2]. Despite their limited use manufactured aggregates have a variety of functions and once their lower weight is taken into consideration they have some advantages (improved thermal & acoustic efficiency, lower unit weight) over natural materials if they can be delivered at a cost effective price for the construction industry. Their primary use is in lightweight construction blocks but they can also be used for lightweight fill, ground insulation layers in buildings and, where they have sufficient strength, in structural concrete. It has been argued by Owens and Newman (1999) that once the lower density of concrete made with lightweight (manufactured) aggregate is factored in, the economics of delivering and using them for a given concrete specification remain favourable despite the higher price of the manufactured aggregate (see Figure 2). Figure 2 suggests that an aggregate of particle density of 1600kg/m^3 although costing £15 per tonne delivered as opposed to £10 for natural aggregates would produce the required C35 (35 N/mm^2 compressive strength) concrete at the same overall cost.

Manufactured Aggregates production plants in the UK are limited in number. There is one in Yorkshire owned by Plasmor that produces an expanded or bloated clay product for its own use, primarily in concrete block production. A further operation used to be in operation producing Lytag™ from PFA at Eggborough power station. However this plant has been closed. Lytag is now imported from Poland in a joint venture with Hargreaves Mineral

Services and future UK plant is being considered. A plant producing a material similar to Lytag is owned by RTAL in Tilbury in Essex, this plant has yet to be fully operational on a commercial basis.

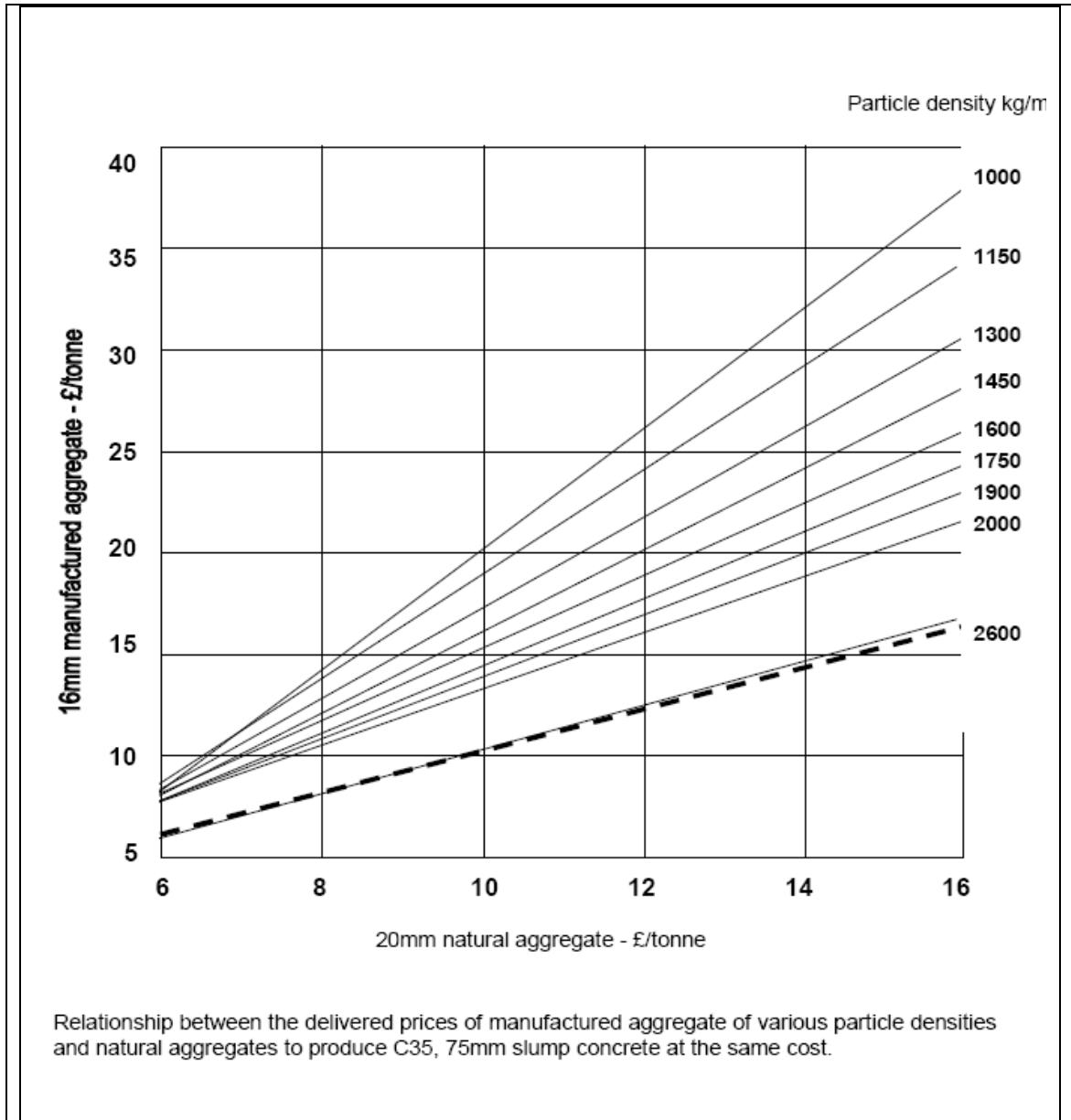


Figure 2: Adapted from Owens and Newman 1999. Prices adjusted for Aggregates Levy. Dashed line indicates natural aggregate

In addition to domestic production other forms of expanded clay aggregate are imported into the UK these are Leca which is imported by Claytek of South Yorkshire; Liapor, which is produced in a number of European countries including Germany, Croatia Hungary, Austria and Switzerland); Maxit Light weight aggregate (which also includes the Fibo-Exclay brand) which in China and Europe and is part of HeidelbergCement. Other brands include Argex in Belgium which incorporates silt and clay from river / canal and harbour dredgings and has a capacity of 500,000 m³.

A further product called Aardelite is produced by curing PFA with lime and a binder. Plants operate in the Netherlands, the United States and India. Unlike the other products discussed Aardelite is not sintered in a kiln or other high temperature process. It relies on chemistry to turn fine powdered material into hard granules suitable for use as aggregates.

In addition to the Aardelite process work has also been undertaken at the University of Greenwich leading to a 'spin-out' company Carbon 8 systems (www.c8s.co.uk/index.htm). Here accelerated carbonation using carbon dioxide gas is used to cure the aggregate and as with Aardelite a cement or binder is usually used.

The use of organic binders is being investigated in a Defra funded research project undertaken by Imperial College, titled: 'New Technologies to Allow Beneficial Reuse of Silt from Construction and Demolition Waste Recycling Washing Plant' - WR0204.

The processing of each of these types of aggregate are discussed in the following section.

2.1 Process overview

The production of manufactured aggregates requires varying degrees of processing depending on the materials being used. To provide an overview of this the production of manufactured aggregate by thermal means (sintering) from bloating clay will be considered followed by an alternative thermal method using PFA. Finally a 'non-thermal' or chemical method will be briefly covered. Many of the unit processing operations are similar for each method described. A simplified process diagram is shown Figure 3.

Bloating clay is the term used for a clay, that when heated to a certain temperature, has minerals that decompose to release a gas whilst at a similar temperature the remaining mineral constituents become soft and plastic in nature (they become pyro-plastic), the evolving gas and plastic nature combine and the clay body expands to produce a fine 'honeycomb' texture.

In the production of expanded clay aggregate the clay is first extracted in conventional methods. It is then stored and stockpiled. At this stage some mixing of the stockpile may occur to ensure consistent composition. The clay is then dried and powdered to enable good control of the agglomeration process. Agglomeration usually occurs on an inclined rotating pan in the presence of a small amount of moisture. The agglomerated pellets may then be dried prior to thermal processing. In some operations the clay may bypass the drying,

powdering and agglomeration stage and may simply be extruded or simply broken up to form the required particle size. Good control during the agglomeration stage can go some way in helping control the quality of the final aggregate. Once the clay is in the form of agglomerated pellets it is screened to remove undersize (and oversize) pellets. The pellets are then fed directly into a rotary kiln and fired at a temperature between 1100 -1200 °C. The rotary kilns are usually fired by fossil fuel burners. On discharging the aggregate will be cooled prior to stockpiling.

The use of PFA for the production of Lytag uses similar production methods to that for clay; however the use of an ash precludes any drying or powdering prior to agglomeration. Figure 4 shows schematics for lightweight aggregate manufacture using a rotary kiln and also provides a photograph of a rotary kiln.

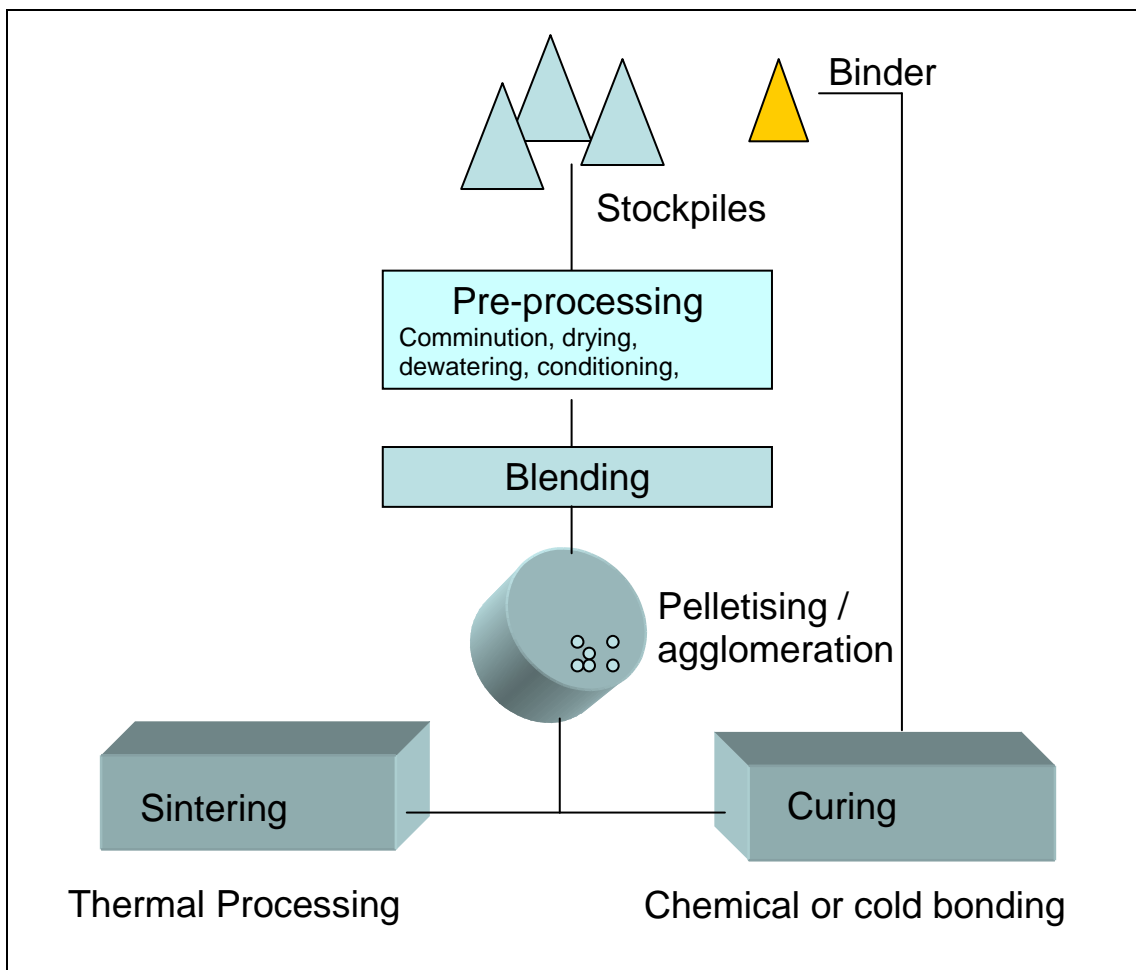


Figure 3: Simplified process diagram of typical manufactured aggregate.

Additionally a use of a travelling grate furnace is preferred to a rotary kiln. The travelling grate furnace is in effect a slow conveyor belt on which the agglomerated pellets are loaded and ignited using a gas fuelled flame. The residual carbon in the PFA is then used as the method of heating by pulling air through the bed from under the grate as it moves. The travelling grate

is operated so as that as the pellets reach the end of the travelling grate they have been fully fired (or sintered) to produce the aggregate.

Chemically bonded manufactured aggregates rely on reactions between minerals often in combination with hydration reactions with water to produce a hard granular material. This will require mineral compositions that have adequate amounts of pozzolanic minerals, calcium silicates and free lime (CaO). In this case the materials are simply blended and agglomerated or extruded into pellets and then cured at temperatures approaching 100 °C to provide the necessary strength. Often a cement or organic binder maybe necessary to help provide the strength required. Figure 4 shows the process diagram for the Aardelite process.

2.2 Sustainability issues

Sustainability issues arise from two sources in manufactured aggregate production, firstly the fuel needed to thermally process the materials and secondly the use of mineral resources. The utilisation of waste in their manufacture however has the ability to offset some of the latter concerns whilst also providing a genuine use for what would otherwise be a waste disposal problem (for example - Lytag using PFA). Research has been undertaken on the incorporation of organic based wastes such as sewage sludge and paper making sludge (Wainwright *et.al.* 2002) and pharmaceutical sludge. Furthermore the Minergy plant that operated in the United States between 1994 and 2000 used PFA and sewage sludge (www.minergy.com). In addition the production of manufactured aggregates, where produced, can offset the need for primary aggregates.

Where manufactured aggregates are lightweight they have the additional benefits of having enhanced thermal properties when incorporated into construction blocks or as under floor insulation and structural fill material. When used in concrete products especially structurally or in pre-cast elements they also reduce the 'dead load' (the strength requirement of a construction elements needed support its own weight) of the concrete structure enabling more effective design and reduce material resource during construction.

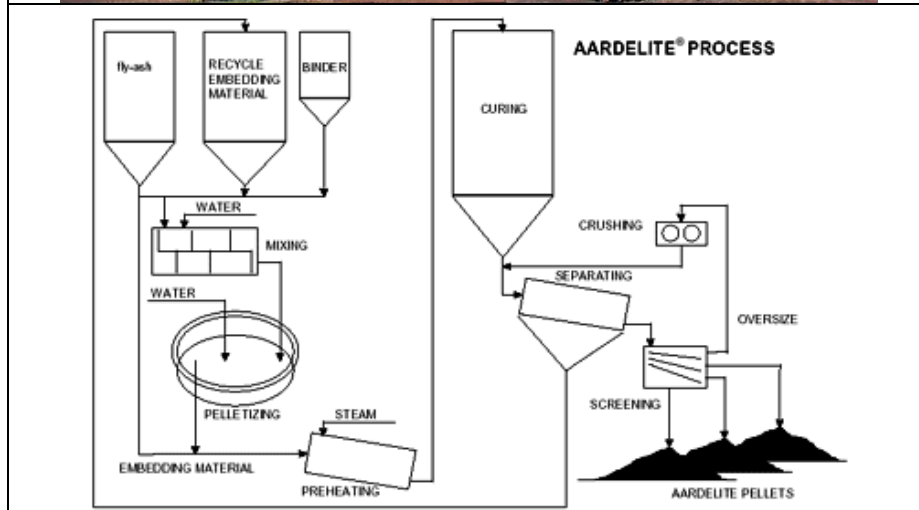
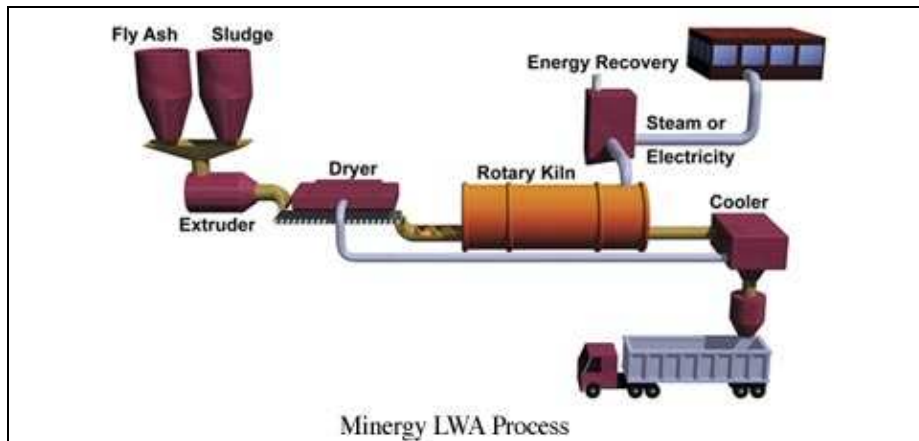


Figure 4: Top - schematic of a manufactured aggregate plant. Middle - Photograph of a rotary kiln. Bottom - Schematic of the Aardelite plant, a chemically bonded manufactured aggregate. Sources (respectively):

http://www.minergy.com/technologies/images/lwa_process.jpg

<http://www.argex.be/indexen.html>

<http://www.aardinglg.com/aardelite-process.html>

3 Alternative raw materials use in manufactured aggregates

3.1 Key requirements

In current manufactured aggregates the important properties of the feedstock materials are all (or mostly) inherent in either the PFA or the extracted clay used to produce the aggregate. For both thermally produced aggregates and those chemically bound (also called cold bonded). The bulk chemistry (SiO_2 , Al_2O_3 , $\text{FeO/Fe}_2\text{O}_3$, CaO); the mineralogy (especially the clay minerals and the rock forming Al/Ca/Mg Silicates); and the particle size distribution (PSD) are all important factors in assessing a suitable alternative mineral material. Contamination by heavy metals is generally to be avoided*. Such characteristics provide important functions to the aggregate - these functions are outlined below:

3.1.1 Body or Filler

As with brick or other ceramic manufacture the main body of manufactured aggregate is made primarily of 'rock forming' minerals and in the case of combustion ashes similar silicates of aluminium, calcium, iron and magnesium in addition to amorphous glassy phases. The function of these minerals is to pack sufficiently closely to provide the structure of the aggregate and provide the strength when processed by sintering or chemical bonding. In expanding clay aggregates this packed structure vitrifies slightly with voids being formed by gases; this weakens the structure but provides a lower density material with enhanced thermal properties. To understand the ability of a material to sinter readily it is important to not only know the bulk chemistry i.e. oxide analysis Al_2O_3 , FeO , SiO_2 , MgO , etc. It is also useful to have an analysis of the mineral phases present as this will help determine and understand likely mineral phase changes.

In the case of chemically bonded aggregate all the material present acts as a body or filler. However there are also active mineral phases present specifically free lime (CaO) which in the presence of water and other silicates mineral will act as a cement. The addition of cement can also produce a material of sufficient strength to act as an aggregate. Additives such as organic binders may also be used to provide mineral-organic composites.

3.1.2 Bloating agent

In expanding clays and other materials the presence of certain minerals will decompose at certain temperatures leading to gas generation that in turn may lead to bloating with the clay / mineral body of the aggregate. Such materials are avoided in brick and other ceramic industries. Riley (1951) provides the seminal work in this area. He cites a number of possible minerals that may lead to bloating including:

* However research has shown that leaching of metals from manufactured aggregate is often much less than that from the original feedstock (waste) material (Wainwright *et.al.* 2002).

Pyrite FeS

Haematite Fe₂O₃

Dolomite MgCaCo₃

In the case of other rock minerals hornblende, biotite and chlorite were also attributed with producing bloating, possibly via intermediate haematite. Other metal sulphide salts may also provide the necessary minerals for bloating. Only small amount of the bloating minerals are needed as the volume change from solid to gas is very large.

Obviously the presence of organic materials produces gas as it combusts during thermal processing however the temperature that this occurs is lower than that needed to sinter the materials and make them plastic enough to bloat.

3.1.3 Fluxing agent

Fluxes reduce the temperature of sintering. The presence of minerals which contain elements such as sodium and potassium will act as fluxes. In addition the presence of amorphous and glassy phases will also help a material flux.

3.1.4 Coatings

It may be possible during processing to add material to the surface of each aggregate particle. This may help reduce water absorption of the aggregate or provide a surface that maybe rougher or more abrasive.

3.1.5 Fuel / Organic material

To reduce the fossil fuel used during thermal processing it is possible to incorporate organic material as a substitute fuel. This material is incorporated during the agglomeration stage. However the combustion of this material complex as it is contained with each aggregate particle.

3.2 Substitute materials - Thermally produced manufactured aggregates

Potential alternative materials in the production of manufactured aggregates that have been tried at research, pilot and commercial scale are shown in Table 1. Comments are also included on current and future potential.

Table 1: List of alternative materials that could potentially produce manufactured aggregate or be added to virgin raw materials (bloating clay) or PFA.

Alternative material	Progress	Function	Comment
Pulverised Fuel Ash	Commercial	Body material some additional fuel	Used commercially in Lytag. Production however not produced in UK. Also forms the base material for the RTAL process
Quarry fines	Research / pilot	Body material	The composition depends on the type of quarry. For a crushed rock it will be the same as primary aggregate. For sand and gravel it will be a mixed clay / silt
Municipal Waste Incinerator - bottom ash	Research	Body material Bloating agent	Needs processing and most likely crushing before use. Concern over sulphate content
Municipal Waste Incinerator - Fly ash / APC residue	Research	Bloating agent	Unlikely to be used commercially due to problems with pollution of heavy metals in the gas produced during sintering and within the product
Incinerated sewage sludge ash - ISSA	Research / pilot	Body material / flux	A good candidate for utilisation. Particle size distribution may need modifying
Fullers Earth (spent)	Commercial	Body material / small amount of additional fuel	Used commercially. The mineralogy does not interfere with bloating during sintering.
Dredgings (river / harbour / canal)	Commercially used	Body material	Used in continental Europe in expanded clay aggregates
Glass (post consumer / industry)	Research / pilot	Flux / coating	Presence of alkali metal oxides and SiO ₂ allows lower firing temperatures and also promotes 'softening' of aggregate during sintering allowing expanded aggregates to be produced.
Excavated Clay	Pilot	Body material	Direct replacement for materials such as PFA however may increase density of aggregate
Construction Demolition & excavation waste filter cake	No research known	Body material	Good possible candidate for research if sufficient quantities can be sourced.

3.2.1 Benefits

In Table 2 the results of potential use of alternative materials thermally produced manufactured aggregates are shown. Benefits and barriers have been classified into six different groups, namely: material related, economic, environmental, legal, organisational and social. A description of the employed classification system has been given in the report on database development also undertaken as part of this project.

Potential benefits on the use of alternative materials in manufactured aggregates fall primarily within the material related, economic, and environmental, categories. Material related benefits

are seen from the reduced use of virgin materials, and from reduced processing. Importantly, for the focus of this study, there are also potential benefits from the availability of alternative material resources that can provide a continuous supply and that show some desirable function in the production of manufactured aggregates. Environmental benefits are seen from diverting waste from disposal and in some cases, such as the inclusion of a fluxing material, a slight reduction in fuel and CO₂ emissions. Finally the use of alternative materials assists the sector to improve its environmental profile and to move towards the production of greener products.

Table 2: Classification the utilisation of alternative materials in the production of manufactured aggregates. Numbers shown in benefits/barriers/ analytical techniques link to **Figure 5**. Categories of benefits/ barriers → MR=material related, EC=economic, ENV=environmental, LE= legal, SO= social, ORG= organisational; ranking system shown in barriers → 1= significant, 2= important, 3= less important, 4= future work will define significance).

Recycled material	Potential Benefits	Potential Barriers	Analysis
Pulverised Fuel Ash	1,3,5,6 MR-EC	2,5 MR-EC = 3	1 to 5 on materials all end products tests
Quarry fines	1, 4,6 MR-ENV	2,5,6 MR-EC-ENV = 3	1,2,3,6 on materials all end products tests
Municipal Waste Incinerator - bottom ash	1,2,3,7,8 MR-EC	2,4,5,6,7 MR-EC-ENV = 2	1 to 6 on materials all end products tests
Municipal Waste Incinerator - Fly ash / APC residue	-	1,2,3,7 MR-ENV-LE = 1	1 to 6 on materials all end products tests
Incinerated sewage sludge ash - ISSA	1,2,3,7,8 MR-EC-ENV	5,6 MR-EC = 2	1 to 6 on materials all end products tests
Fullers Earth (spent)	1,2,5,8 MR-EC-ENV	-	2,5,6 on materials all end products tests
Dredgings (river / harbour / canal)	1 to 8 MR-EC-ENV-ORG	2,5,7,8 MR-LE-EC-ENV = 2	2 to 6 on materials all end products tests
Glass (post consumer / industry)	1,4,5,7 MR-EC-ENV	4,6 MR-EC-ENV = 3	1, 3 on materials all end products tests
Excavated Clay	1,2,4,6 MR	2,5 MR-EC = 2	2 to 6 on materials all end products tests
Construction Demolition & excavation waste filter cake	1 MR	1,5 EC = 2	1 to 6 on materials all end products tests

3.2.2 Barriers

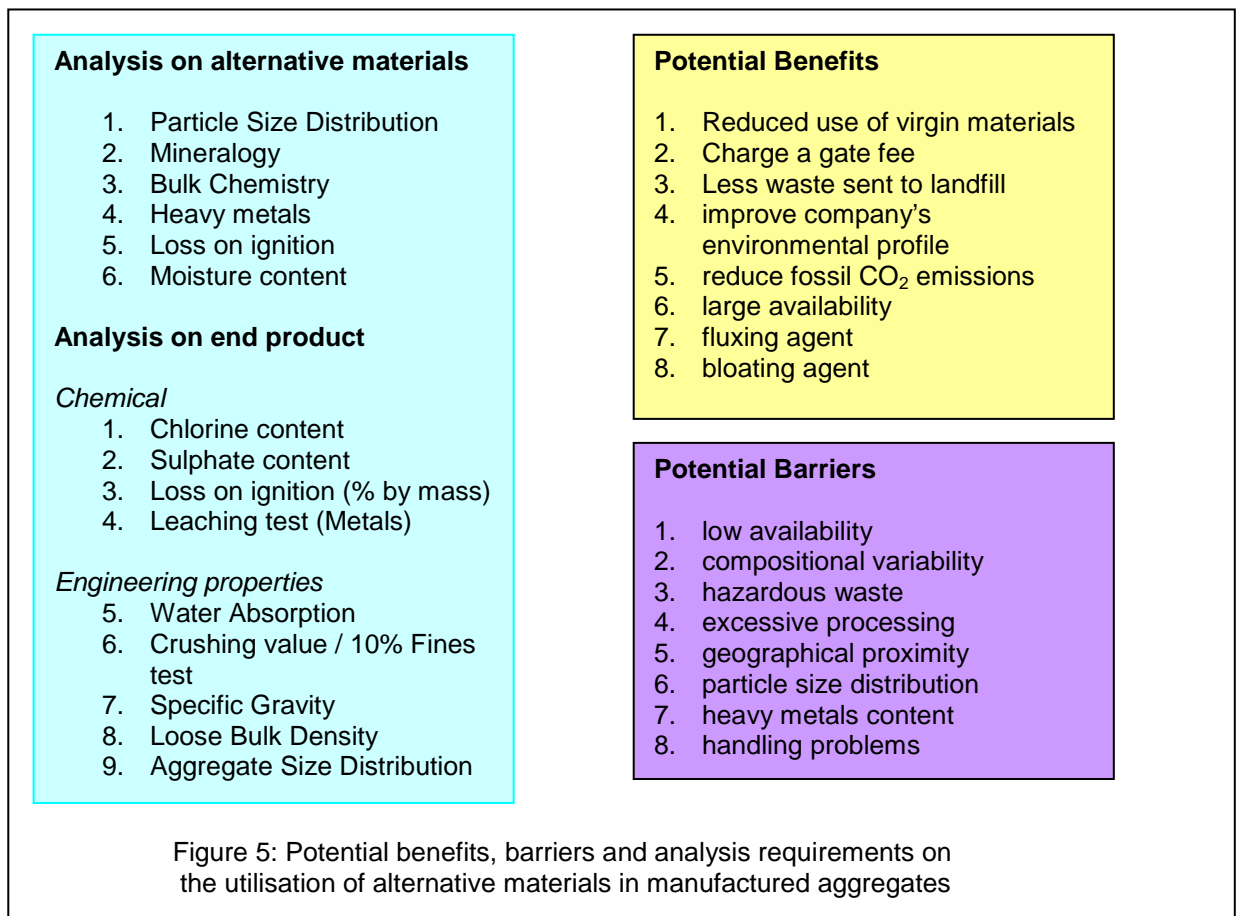
The majority of barriers seen from the use of alternative materials (Table 2) are material related. Parameters such as the low availability of adequate quantities of resources, the compositional variability, or adverse minor elements in the composition of waste derived materials (i.e. heavy metals), as well as the lack of geographical proximity of a desirable source, may discourage or prohibit their use. For example, dredged sediments, quarry fines and PFA all need to be proximal to the manufacturing aggregate production plant. Economic barriers are seen from additional handling and processing. Two examples are the use of municipal solid waste incinerator bottom ash (MSWI BA) which may need comminution and screening for achieve the correct particle size distribution and to remove metals and the need

to dry dredged sediments prior to utilisation. Legislative barriers are seen from the composition of waste, in particular with materials that have been classified as hazardous (municipal solid waste incinerator fly ash for e.g.). A ranking system has been employed to define the significance of the reported constraints ranging from 1, being significant, to 4, meaning that future work is required to determine its importance.

Another important barrier that the sector would have to face is the large continuous supply of consistent material. An operation with a consistent supply of clay or PFA would provide a clear benefit to the operator such as desirable properties, or a profit (maybe from charging a gate fee) to be an attractive option.

3.2.3 Analysis

Table 2 shows that all end product tests will be required (Figure 5) for all manufactured aggregates produced; this is to ensure an understanding of their appropriateness for intended use (in a concrete block or as lightweight fill for example). Key alternative material analysis is particle size distribution and mineralogy the former to understand the potential for agglomeration (less important for clay materials) and the latter to assess the ability to sinter and maybe bloat.



3.3 Substitute materials - The use of alternative fuels in thermally produced manufactured aggregate

The incorporation of organic material into the mineral matrix of manufactured aggregate prior or during the agglomeration process is undertaken to primarily provide some of the fuel required to sinter the material. The organic material is usually incorporated as sludge. The volume used has been shown to be up to 10 % by dry weight of the mineral material. Table 3 shows the four possible materials and is based on work undertaken at the University of Leeds and the company RTAL (Wainwright *et. al.* 2001).

Table 3: List of potential organic materials may be incorporated in manufactured aggregates as an alternative fuel

Recycled material	Progress	Function	Comment
Pharmaceutical sludge	Research	Fuel	Potential health and safety and legislative problems.
Paper Sludge	Research / pilot	Fuel / body material	A good candidate for commercial use. Paper fibres add fuel and the clay provides useful minerals
Sewage Sludge	Research / commercial	Fuel	Potential health and safety problems in handling. Odour nuisance. High potential for utilisation if these barriers can be overcome
MSW putrescible fraction	Research	Fuel	Numerous handling problems and contamination with materials such as plastic.

Table 4 presents the potential of utilisation of alternative fuels in manufactured aggregate production. Benefits seen from the use of alternative fuels are mainly environmental, but economic, and material and related benefits are also to be found. The conservation of fossil fuel resources, the reduction of CO₂ emissions, the waste co-processing opportunities, the recycling of combustion residues and the diversion of waste from disposal are the major environmental advantages of this utilisation.

Table 4: Classification the utilisation of alternative fuel in the production of manufactured aggregates. Numbers shown in benefits/barriers/ analytical techniques link to **Figure 6**. Categories of benefits/ barriers → MR=material related, EC=economic, ENV=environmental, LE= legal, SO= social, ORG= organisational; ranking system shown in barriers → 1= significant, 2= important, 3= less important, 4= future work will define significance).

Recycled material	Potential Benefits	Potential Barriers	Analysis
Pharmaceutical sludge	1 to 8 EC-ENV	1,2,3,4,7,8,10 MR-LE-ORG = 1	1 to 6
Paper Sludge	1 to 8 EC-ENV	2,5,7,10 MR-ORG = 3	1 to 6
Sewage Sludge	1 to 8 EC-ENV	2,3,5,6,7,8,10 MR-LE-ORG = 2	1 to 6
Municipal Solid Waste - putrescible fraction	1 to 8 EC-ENV	1,2,3,4,5,6,7,8,10,11 MR-LE-ORG = 1	1 to 6

3.3.1 Benefits

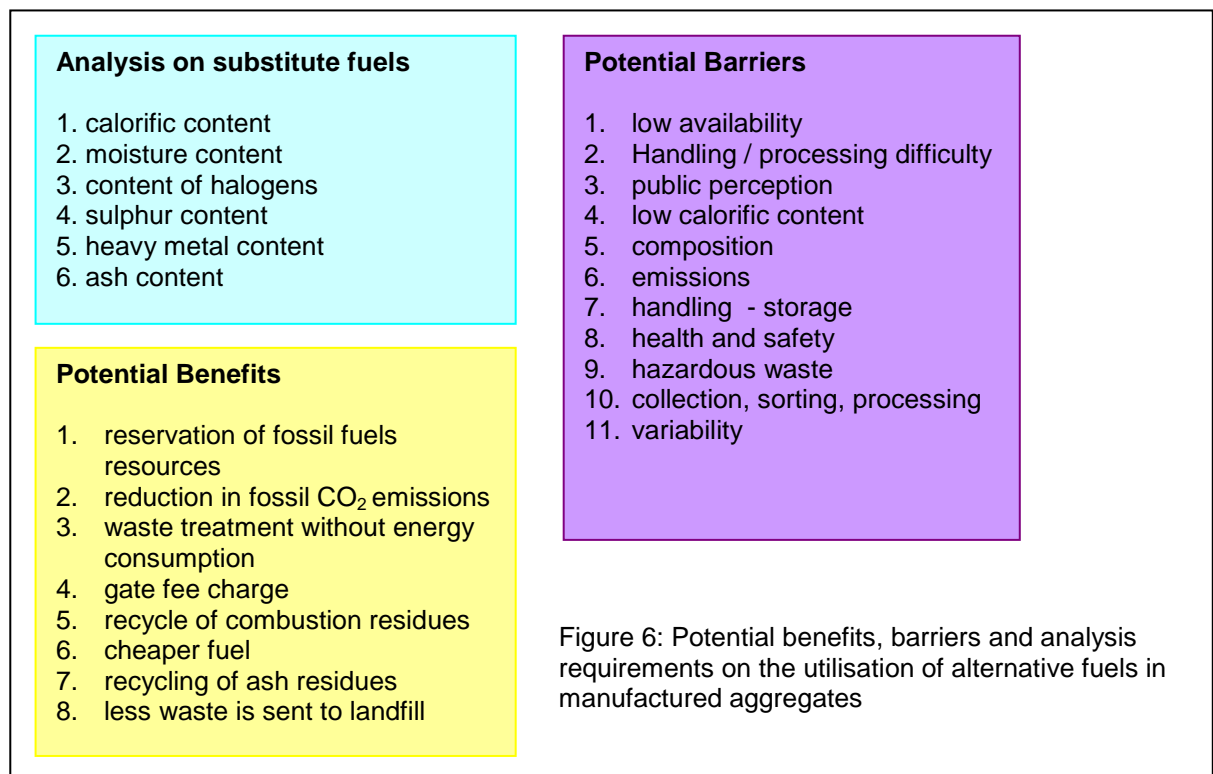
The use of alternative fuels would be economically beneficial for a manufactured aggregate plant, particularly when revenue can be made by charging a gate fee to waste producers. Environmental benefits include the reduced fossil fuel CO₂ emissions and reduced waste to disposal.

3.3.2 Barriers

Barriers associated with the use of organically derived fuels fall within the material related and environmental classes. The organic sludges can be difficult to handle and incorporate (mix) into the mineral matrix. It may require large amounts of energy to do this especially if dewatering or drying is needed. Additionally variability in the sludge especially moisture content would upset processing conditions markedly. In the case of sewage sludge the presence of flocculent also may create handling difficulties. Legal, organisational and social barriers also need to be considered when working with such odorous wastes that have a negative public profile and may include contamination.

3.3.3 Analysis

To fully understand the impact of incorporating organic materials on the thermal process and the associated gaseous emissions it is necessary to undertake all the analyses suggested in Figure 6.

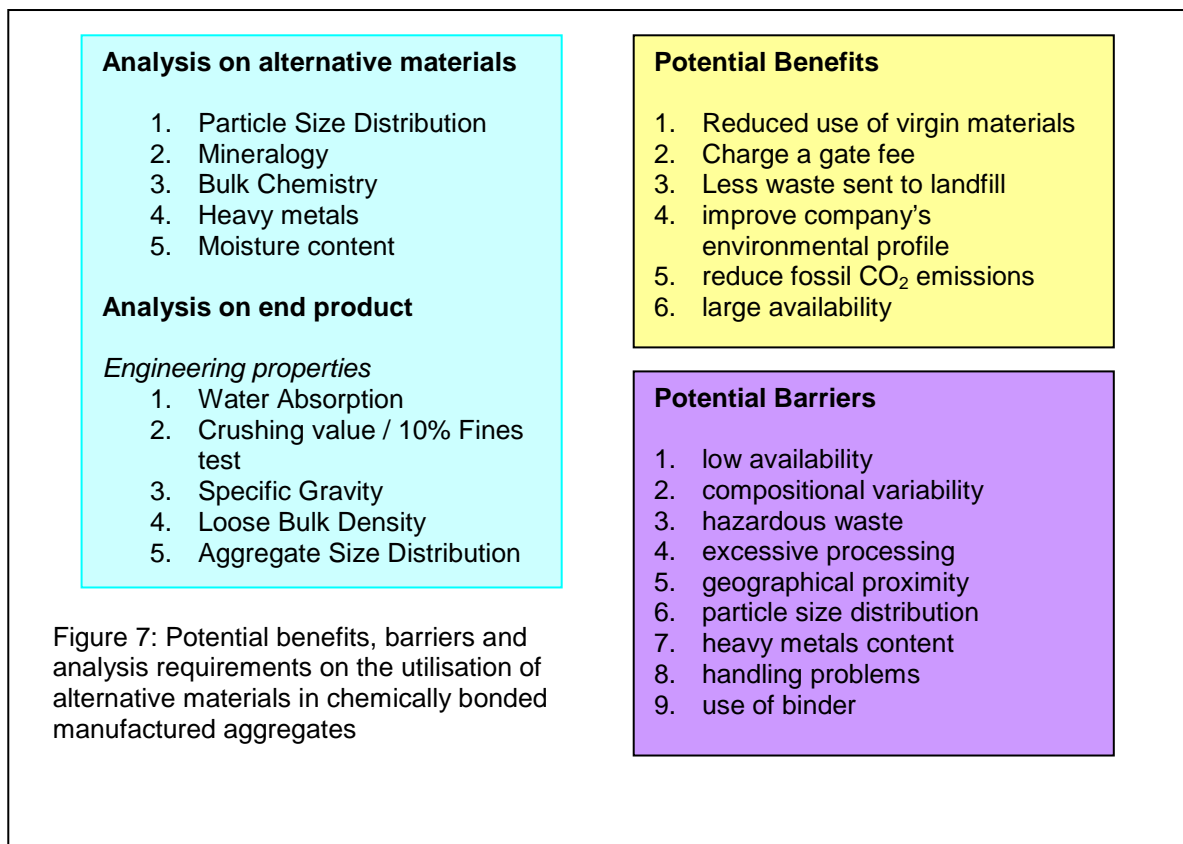


3.4 Substitute materials - Chemically bonded manufactured aggregate

Table 5 shows materials that have been tried on a research basis or commercially (by Aardelite) for the production manufactured aggregates.

Table 5: Classification the utilisation of alternative materials in the production of manufactured aggregates. Numbers shown in benefits/barriers/ analytical techniques link to **Figure 7**. Categories of benefits/ barriers → MR=material related, EC=economic, ENV=environmental, LE= legal, SO= social, ORG= organisational; ranking system shown in barriers → 1= significant, 2= important, 3= less important, 4= future work will define significance).

Recycled material	Potential Benefits	Potential Barriers	Analysis
Pulverised Fuel Ash	2-6 MR-EC-ENV	5, 9 ENV-EC	All on materials and end products
Quarry fines	2-6 MR-EC-ENV	9 ENV-EC	1 All on materials and end products
Municipal Waste Incinerator - bottom ash	2-6 MR-EC-ENV	2,5 7, 9 MR-ENV-EC	All on materials and end products
Contaminated Land	1-6 MR-EC-ENV	2,5 7, 9 MR-ENV-EC	All on materials and end products
Incinerated sewage sludge ash - ISSA	1-6 MR-EC-ENV	2,5 7, 9 MR-ENV-EC	All on materials and end products
Construction Demolition & excavation waste filter cake	2-6 MR-EC-ENV	9 ENV-EC	All on materials and end products



3.5 Characterisation framework

Figure 7 presents the proposed characterisation framework on the use of alternative materials in the production of manufactured aggregate. Alternative materials are classified according to the function they contribute to the process or final product. The proposed characterisation framework is expected to initiate / facilitate material exchanges and to find application as a guidance tool both for waste producers and waste users. Waste producers could benefit by identifying whether manufactured aggregate could be a possible output for their waste. On the other hand, aggregate manufacturers could implement a similar type of categorisation to gain additional knowledge and ideas on “new” alternative materials and their fit into the process.

Figure 7 also shows two possible scenarios in which various alternative raw materials can be combined to produce manufactured aggregates. For further examples of potential mixes see Wainwright *et.al.*(2002), (Wainwright *et.al.* 2002).

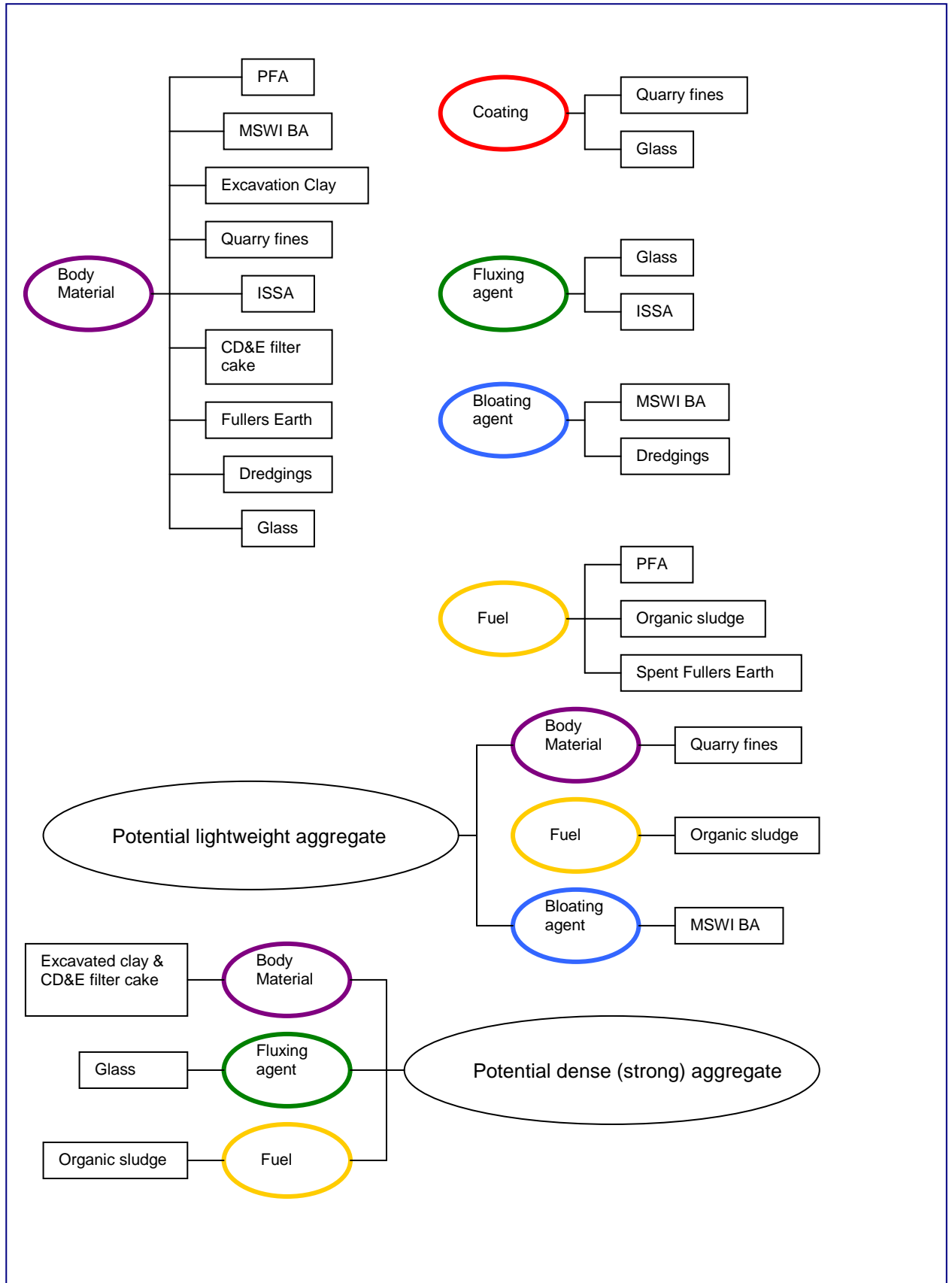


Figure 8: Characterisation framework on the utilisation of alternative raw materials in manufactured aggregates including theoretical mixes of materials that could be used to produce manufactured aggregate.

3.6 Standards and protocols

A quality protocol is currently being produced for pulverised fuel ash (PFA) and others are anticipated for other materials. These protocols are intended to define both compositional and quality requirements and also the sources of target 'wastes' as "by-products" (Environment Agency, 2007). This will have knock on effects for the use of PFA as a potential feedstock for manufactured aggregate as it makes PFA increasingly eligible for alternative uses. These protocols are primarily concerned with use in bound and unbound materials and not into manufactured aggregate *per se*. As the aggregate production process means the ash is thermally and chemically transformed the aggregate produced is not considered to be a waste.

The definition of waste and by-product is also covered by a recent Communication from the European Commission [COM(2007) 59 final]. It defines a "*three part test that a production residue must meet in order to be considered as a by-product.....where the further use of the material was not a mere possibility but a certainty, without any further processing prior to reuse and as part of a continuing process of production, then the material would not be a waste. This test is cumulative – all three parts must be met.*" This may open up some materials to be used directly (if there is no or only minor processing - screening perhaps) in manufactured aggregate.

Standards for lightweight aggregate are numerous in terms of testing the end product i.e. concrete. However, BS / EN 13055 *Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout* is the main standard to be considered on the actual aggregate.

4 Guidance on accessing alternative raw materials for Manufactured Aggregates

4.1 Waste exchange

As with the cement sector, the manufactured aggregate sector could follow a version of the anchor-tenant model* and develop symbiotic relationships with various local or regional companies that provide materials for aggregate manufacture. The benefits seen from industrial symbiosis are continuity of supply, long term security, mutual dependency and therefore mutual growth and development. Currently material exchanges taking place are

* More information about the *anchor-tenant* model can be found in the Industrial symbiosis and waste exchange concept *report* (Petavratzi and Barton 2006)

based on simple waste exchanges, but away forward would be for the sector to look to transform such exchanges to symbiotic linkages.

According to this model aggregate manufacture represents an anchor industry; however they would need to be close to a supply of the base mineral material. This could be a power station as with Lytag or the RTAL plant in Essex where it is based next to both a coal fired power station (supplying PFA) and a waste water treatment works (providing sewage sludge). It could then act as a sink for other local materials that could be used either to create slight variations in aggregate properties. Other locations could be next to large quarries (or quarry complexes in the case of sand and gravel operations) or freight transport nodes, for example the Isle of Grain aggregate wharf where a filter cake is produced from crushed rock washing. Different industries could also provide material. If this were the case it may mean operating two processing lines to enable different materials to be produced.

In the case of existing or future expanded clay operations a more straight forward anchor tenant model could be followed. However research on the process and potential alternative additions could be undertaken using this sector review as a starting point.

4.1 Future developments

In linking the sustainability issues with the characterisation framework Initiatives such as the Aggregates Levy, sustainability agendas and relevant legislation on the conservation of natural resources are expected to work as drivers for the production and use of manufactured aggregates containing alternative mineral materials. By substituting part of virgin raw materials with waste-derived ones, or manufacturing aggregates solely from alternative materials (analogous to Lytag), the operator (and therefore the sector) will obtain a higher eco-efficiency image. A further advantage may be to help companies to meet their environmental policy and corporate social responsibility obligations to shareholders. This latter point also applies to developers & companies that specify the use of 'recycled' material in new construction.

The Green Guide for Specification and BREEAM, both of which provide an assessment of environmental impact of buildings or components, include within their assessments a significant element associated with global warming. They also take into account (positively) the use of recycled materials instead of primary materials. The ability to be able to use cost effective lightweight aggregate will help thermal and material efficiency of buildings.

In January 2007, the European Expanded Clay Association (EXCA) was founded. EXCA has 15 member companies but no representative from the UK. Two EXCA working groups have been established on *Standards and Use & Production and Environment*.

5 Overview roadmap for utilising alternative materials in Manufactured Aggregates

As there is no trade body in the UK and only a very limited commercially active industry there are no strategic developments in moving the industry toward utilising alternative materials. During discussions with those organisations that have a UK interest (manufacture and import) it was apparent that the utilisation of alternative materials was seen as desirable. There was also consideration of potential new plants.

Given that many of the construction industry drivers affect changes in the upstream industry these drivers are appropriate to manufactured aggregates, these drivers are:

Technological

- Modular build and off-site construction
- Thermal mass

Environmental

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

Economic

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

The provision and utilisation of manufactured aggregate may help alleviate some of these concerns. However a full life cycle understanding of manufactured aggregate production and utilisation (including in use) needs to be undertaken.

Potential benefits of alternative raw materials in manufactured aggregate
<ul style="list-style-type: none">○ Material related: substitution of raw materials○ Economic: profit through charge of a disposal ("gate" fee), reduced cost of fuels○ Environmental: Reduced CO₂ emissions, conservation of natural resources, recycle combustible residues○ Organisational: generate company and industry environmental profile for green products, better flexibility in raw materials sourcing○ Legal: Good practice may cause wastes to become by-products (through quality protocols)○ Social: cleaner environment, waste management, less extraction

Potential barriers to alternative raw materials in manufactured aggregate
<ul style="list-style-type: none"> ○ Material related: Reduced selling price due to density increase, Logistics, continuity of supply, geographical proximity, variability, undesirable properties, health and safety issues ○ Economic: Additional costs of handling, testing, trials, storage, processing requirements, monitoring, licensing, transport ○ Environmental: increased emissions ○ Organisational: Additional installations, corporate responsibility ○ Public perception of the utilisation of wastes

Future work:
<ol style="list-style-type: none"> 1) Greater understanding of aggregate manufacturing process - knowledge transfer between Academia and industry (both ways) 2) Evaluation by large waste producers (quarries, power stations, Municipal Solid Waste incinerators, and other) of the potential for new manufactured aggregate markets 3) Evaluation by large waste producers (quarries, power stations, Municipal Solid Waste incinerators, and other) of the potential for their wastes and by-products to lead to new manufactured aggregate sites.

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