

The use of recycled and secondary materials in residential construction



Guide

NHBC Foundation

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About the NHBC Foundation

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy technologies and the earlier investigation of what zero carbon means to homeowners and house builders.

The NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

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Glossary

Aggregate	Granular material used in construction. Primary aggregate is material such as sand, gravel and crushed stone, taken from natural sources specifically for use as aggregate. Recycled aggregate is material produced by the processing of selected inorganic material previously used in construction. Secondary aggregates are generally by-products of mining, quarrying or industrial processes.
Air-cooled blastfurnace slag	By-product from the blast furnaces used to make iron. The slag is periodically tapped off from the process as a molten liquid and cooled in pits. The cooled material can be processed to produce construction aggregate.
Basic oxygen steel (BOS) slag	See steel slag.
Bound aggregates	Term used by current standards for materials made up of graded and blended aggregates that are used in construction with the addition of a binding agent such as bitumen, cement or other hydraulic binders.
BREEAM	World's foremost environmental assessment method and rating system for buildings, with 200,000 buildings with certified BREEAM assessment ratings and over a million registered for assessment since it was first launched in 1990. BREEAM sets the standard for best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely recognised measures of a building's environmental performance.
Coarse aggregate	For the purposes of this guide, coarse aggregate is defined as having a particle size exceeding 4 mm.
Code for Sustainable Homes	Measures the sustainability of a home against design categories rating the whole home as a complete package. The design categories include energy, CO ₂ , pollution, water, health and well-being, materials, management, surface water run-off, ecology and waste.
Cohesive fill	Contains mainly materials that give handling, placement and subsequent engineering performance similar to that of a fine cohesive soil.
Compaction	Process of densifying soils by some mechanical means such as rolling, ramming or vibration to reduce the volume of voids.
Compression	Reduction in the volume of fill with time under constant imposed load. Fill that is initially loosely placed and dry may suffer collapse compression if it later becomes wet.
Consolidation	Reduction in the volume of ground resulting from the expulsion of pore water due to imposed static loading or a reduction in groundwater pressure (drainage).
Designated concrete	Concrete mix selected from a restricted range given in BS 8500-2 ^[1] , where the producer must hold a current accredited product conformity certification approved to the quality standard BS EN ISO 9001 ^[2] .
Designed concrete	Concrete mix with a requirement for strength; this strength requirement may be satisfied by using a designed concrete where the specifier states the limitations on the mix design (eg in industrial ground floor slabs), or a designated concrete, where a supplier accredited by a third party designs the mix to suit the requirements of the designation given by the specifier.
Engineered fill	Fill that is selected, placed and compacted to an appropriate specification, so it will exhibit the required engineering behaviour.
Fill	Ground that has been formed by material deposited by human activity rather than geological processes. It is alternatively termed made ground and man-made ground. When used to fill an excavation or placed behind a retaining wall, it is termed backfill. When placed within an enclosed space, it is termed infill.

Granular fill	Contains mainly material of significant particle size so it appears to consist of easily distinguishable separate particles and would be expected to behave similarly to a coarse soil.
Ground granulated blastfurnace slag (ggbs)	By-product from the blast furnaces used to make iron. The slag is periodically tapped off from the process as a molten liquid. If it is to be used for the manufacture of ground granulated blastfurnace slag it is rapidly quenched with water. Quenching produces granulates similar to coarse sand. This granulated slag is then dried and ground to a fine powder.
Hardcore	Imprecise general term for engineered infill material placed within the confines of a building foundation in order to support a ground-floor slab or an oversite concrete slab.
Hydraulically bound mixtures (HBM)	Hydraulically bound mixtures set and harden by hydraulic reaction. They include cement stabilised material (ie mixtures based on the fast setting and hardening characteristics of cement). They also include hydraulically bound mixtures based on slow setting and hardening binders made from industrial by-products such as pulverised fuel ash (known as fly ash bound material) and blastfurnace slag.
Incinerator bottom ash aggregate (IBAA)	IBAA is processed from the incinerator bottom-ash material discharged from the burning grate of municipal solid waste (MSW) incinerators. It is a mixed material that may contain varying proportions of glass, ceramics, brick and concrete in addition to clinker and ash.
Non-engineered fill	Fill material that has arisen as a by-product of human activity, often involving the disposal of waste materials; it has not been placed to facilitate a subsequent construction application.
Optimum water content	Water content at which a maximum dry density of fill is achieved using some specified compaction procedure.
Prescribed (ready-mixed) concrete (see BS 8500-1^[3])	Mix for which the purchaser prescribes the exact composition and constituents of the concrete and is responsible for ensuring that these proportions produce a concrete with the required performance. Effectively the purchaser selects the materials and mix proportions to satisfy the required strength and durability needs but does not specify these parameters. Mix is ordered by its constituent materials and the properties or quantities of those constituents to produce a concrete with the required performance. The assessment of the mix proportions will form an essential part of the conformity (compliance) requirements if the purchaser so requires.
Primary aggregates	Granular material used in construction produced from natural materials.
Pulverised fuel ash (pfa)	Residual solid material from the combustion of coal in coal-fired power stations. Pulverised fuel ash is the fine ash recovered from the gas stream, while furnace bottom ash (FBA) is the coarse ash recovered from the bottom of the furnace. Pulverised fuel ash is also known as 'fly ash' or 'coal fly ash' within standards, scientific literature and in countries outside the UK.
Recycled aggregate not defined as RA	The term 'recycled aggregate' is commonly used to denote aggregates produced by processing inorganic materials previously used in construction (see 2.1).
RA	Recycled aggregate principally comprising crushed masonry. The concrete standard BS 8500-2 ^[1] gives further details on compositional requirements for recycled aggregate.
Recycled concrete aggregate (RCA)	Recycled concrete aggregate principally comprising crushed concrete. The concrete standard BS 8500-2 ^[1] gives further details on compositional requirements for recycled concrete aggregate.
Standardised prescribed concrete	Concrete mix selected from a restricted range given in BS 8500-1 ^[3] , where the purchaser is to ensure that the concrete is not used where other aggressive chemicals are present in the ground.
Steel slag	By-product from the furnaces used to make steel. There are two main types electric arc furnace (EAF) steel slag derived from carbon steel or stainless steel production in an electric arc furnace and basic oxygen steel slag (BOS) derived from steel production in a basic oxygen furnace. The cooled materials can be processed to produce construction aggregate.

Sustainable urban drainage systems (SUDS)	Technique to manage surface and groundwater regimes sustainably by measures intended to reduce eg flood risk, maintain or restore natural water flow. Permeable paving can contribute to these aims.
Unbound mixtures	Term used by current standards for materials made up of graded and blended aggregates that are used in construction without the addition of a binding agent such as bitumen or cement.
Vibro stone columns	Most commonly specified ground improvement method, due to the fact that they can be tailored to meet a wide variety of bearing capacity and settlement requirements and provide an economical and sustainable alternative to traditional piling and deep foundations.

Foreword

The use of recycled and secondary materials as aggregates in construction for applications such as pipe bedding and concreting aggregate (as well as in the more 'traditional' uses as 'hardcore', fill and road materials) is increasing. Current estimates indicate that up to 25% of construction aggregates come from recycled and secondary sources. Interestingly, the UK has the highest proportion of aggregate demand met from recycled and secondary aggregates in the EU, with further increases predicted in the future.

The sustainability benefits of correctly using recycled and secondary construction materials (such as aggregates and cement replacement materials) are understood; their use supports the Government's sustainability agenda and gives developers credits for use of recycled content in construction projects. Conversely their incorrect use can lead to unsatisfactory performance and the need for costly remedial works. This clear, detailed and practical guide describes how to source, correctly specify and use secondary and recycled materials in residential construction (illustrated by case studies and examples). It also provides key information on how to avoid incorrect use (and consequent unsatisfactory performance) of recycled and secondary materials.

Existing guidance is available to specifiers and developers, ranging from national standards for aggregates and the various Series documents of the Highways Agency's Specification for Highway Works, to the wealth of downloadable information and resources produced by organisations such as WRAP and the main trade associations. However, this guidance is widely dispersed and also needs to accommodate a range of construction sectors; this can make it difficult for individual sectors of the industry to correctly specify and use suitable materials, thereby mitigating risk.

This guide seeks to share pragmatic and relevant guidance and good practice to the home-building industry. I hope that you will find the guide both useful and informative and that it will help builders, developers and other interested parties to better meet the sustainability agenda while becoming more resource efficient.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation



1 Introduction



There is a great deal of interest within the construction sector, and from their clients, in the greater use of recycled and secondary materials for construction. This guide, which is targeted mainly at developers, specifiers and contractors across the construction residential sector, can be used to:

- Gain an overview of recycled and secondary aggregates, their benefits and applications.
- Find out how to obtain and specify recycled and secondary aggregates.
- Avoid common pitfalls in choice and use of aggregate materials.
- Access case studies and examples of the proper (and some inappropriate) uses of aggregates in residential construction.
- Identify key written resources and information.
- Gain awareness of low carbon cements and the main cement replacement materials available for use in concrete.

The use of recycled and secondary aggregates in a range of construction applications within the perimeter of residential properties (including driveways) provides the main focus for this guide. Related applications such as estate roads, utilities and shared car parking areas are not covered in detail although many of the principles covered here will still apply.

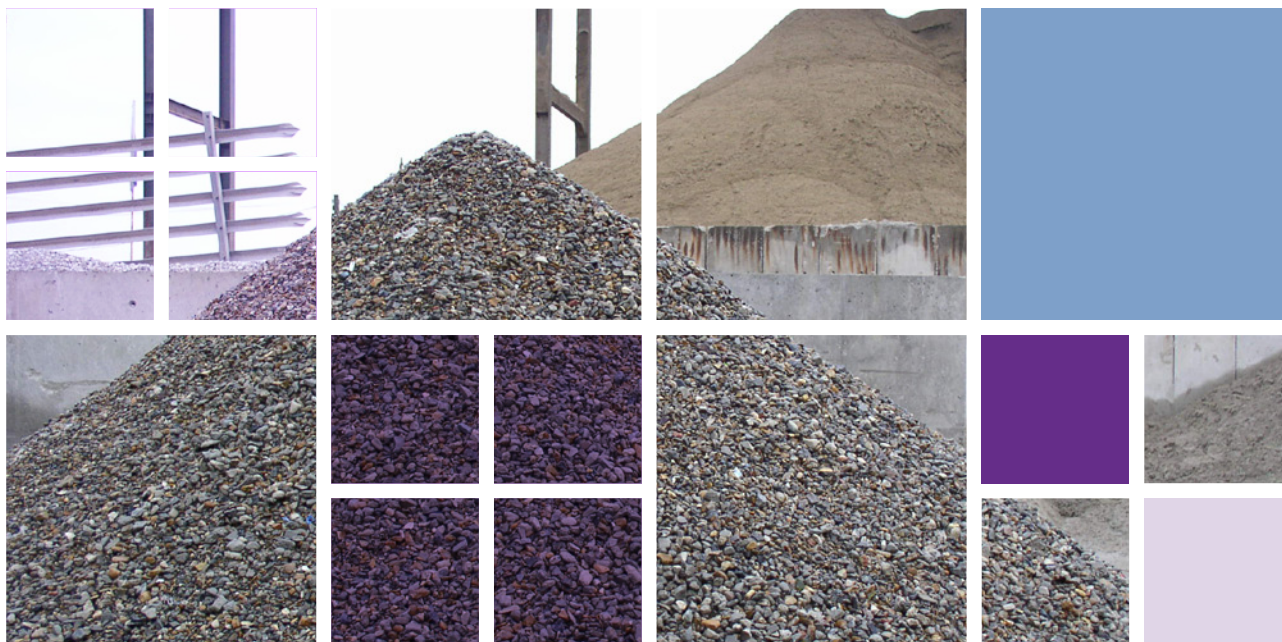
Key sources of information within the guide are:

- Table 2: An introduction to the main uses of recycled and secondary aggregates in residential construction.
- Table 4: A quick reference to the relevant documents, codes and standards by end use application.

- Table 5: Examples of what to order.
- Appendix D: A reference table outlining the opportunities to use recycled and secondary aggregates in different residential applications.

This guide includes highly detailed technical information which will mainly be of interest to large specifiers and developers. Useful resources on recycled aggregates (that are more specifically targeted at small and medium-sized businesses), are provided by Business Link via their website^[4]. Opportunities to use low carbon cements and cement replacement materials are briefly reviewed in Appendix G of this guide. Other (non-mineral-based) construction materials or products such as recycled plastics, cellulose fibre insulation made from, for example, recycled newspaper are outside the scope of this guidance. However, the WRAP reference guide *Opportunities to Use Recycled Materials in House Building* gives further information^[5].

2 Background to construction aggregates



Construction aggregates are the most commonly used construction materials in the UK. While they are relatively low in cost, they are economically and environmentally very important since they are used in such large quantities. Aggregates are normally defined as 'hard, granular materials' that are suitable for use, either on their own (unbound) or with the addition of a binder eg cement, lime, bitumen. Important applications of 'bound' aggregates in residential construction include their use in concretes and mortars. Common 'unbound' applications include using constructional fill (for instance, to raise or level the surface of a construction site), and as drainage materials (in pipe surrounds or bedding, drains and soakaways) and also as fill to support floor slabs.

Bodies such as WRAP, the Mineral Products Association (MPA) and Business Link provide extensive free guidance and supporting information (via their websites) to enable the appropriate use of recycled and secondary aggregates.

2.1 Recycled and secondary aggregates: some definitions

The majority of the UK's construction aggregates come directly from primary (ie natural) sources such as dredged or quarried sands and gravels or crushed rock. However, non-primary aggregates (which are the subject of this guide) are also widely used. They can be broadly placed into two main groups.

1. **Recycled aggregates** arise from various sources including demolition and construction of buildings and structures or from civil engineering works. Examples include crushed concrete, crushed masonry, asphalt planings from the resurfacing of roads, and spent railway track ballast. Recycling involves processing the waste to produce appropriate particle size grading and remove any contaminants, and the application of quality assurance procedures. The formal definition of recycled aggregate according to BS EN 12620:2002 + A1, 2008^[6] is 'aggregate resulting

from the processing of inorganic material previously used in construction'. Certain standards such as BS 8500 include a subclass of recycled aggregates, denoted RA, which is defined as mostly containing crushed masonry.

2. Secondary aggregates are produced as a by-product of mining or quarrying activities or as a by-product of other industrial processes. They can be further subdivided into manufactured and natural, depending on their source. Examples include by-products of china clay and slate extraction, coal power generation and metals extraction and processing. Many secondary aggregates have (or will have) their own quality protocols, or other arrangements in place.

Under the European Standards for aggregates, mineral wastes (eg china clay by-products), are included in the definition of natural aggregates, whereas the aggregates derived from industrial processes are defined as manufactured aggregates. These European Standards do not use the term secondary aggregates, although they are still covered (but under a different name).

The topic of aggregates is littered with (sometimes confusing) terminology and definitions. The term recycled aggregate is often used to refer to materials derived from the construction and demolition industries and sometimes collectively to refer to all recycled and secondary aggregate materials. However, care is needed on the part of the reader as the specific term recycled aggregate (known as RA or RA aggregate) has a different and clearly defined meaning in standards (particularly in the two parts of the standard for concrete, BS 8500:2006).



Figure 1 An in-situ crusher producing recycled concrete aggregate (RCA)

2.2 Quality of recycled and secondary aggregates

It is important to appreciate that the term recycled and/or secondary does not imply low quality. These aggregates include a large range of materials as defined and listed by European and UK Standards and are quality assured against strict quality protocols related to their end use. The products include well proven material used as aggregates, some of which are natural and some of which are manufactured. An example of processed recycled and secondary materials is shown in Figure 1. As a result of the WRAP *Quality Protocol for the Production of Aggregates from Inert Waste*^[7] (known as the Aggregates Quality Protocol), more rigorous testing of chemical and physical properties may in practice be applied to recycled aggregates than would be the case at a conventional quarry extracting natural materials.

Two of the main barriers to the wider adoption of recycled aggregates as quality products have been associated with quality assurance and a lack of clarity about when processed material ceases to become a waste. Box 1 gives details of why the Aggregates Quality Protocol is important to producers, users and specifiers of recycled aggregates.

Box 1 The WRAP *Quality Protocol for the Production of Aggregates from Inert Waste*^[7]

The WRAP *Quality Protocol for the Production of Aggregates from Inert Waste* (the Aggregates Quality Protocol) provides a uniform control process for producers, from which they can reasonably state and demonstrate that their product has been fully recovered and is no longer a waste. It also provides purchasers with a quality-managed product to common aggregate standards, which increases their confidence that the product is fit for purpose. The Aggregates Quality Protocol was produced in the UK by WRAP, in conjunction with the Mineral Products Association, the Highways Agency and the Environment Agency.

The Aggregates Quality Protocol sets out the general procedures to be followed by the aggregate producer in respect of acceptance criteria for incoming waste, establishing an audit trail and testing the output aggregate material in a manner appropriate to the end use. It suggests properties that it may be relevant to measure (quoting relevant test standards), but it does not set any limits for the end use of material. National guidance for testing the grading and properties categories applicable to each end use for aggregates used in the UK are found in the PD 6682 Series of Published Documents. These are useful standards-type documents (produced by BSI) that support, but do not have the same status as a British Standard. It is essential that the principles within the PD 6682 Series are followed. A full list is given in Appendix E of this guide.

WRAP's AggRegain website (http://aggregain.wrap.org.uk/quality/quality_protocols) provides a comprehensive range of documents and resources including contract notes, purchase orders, checklists, specimen contract clauses and guidance notes for use by specifiers to support the application of the Aggregates Quality Protocol.

It is important to emphasise that if recycled aggregates are not produced and supplied in accordance with the Aggregates Quality Protocol those purchasing such recycled aggregates will still have to meet the Waste Regulations and all that is required therein. It is only through the Aggregates Quality Protocol that 'end of waste' is accepted by the Environment Agency (and the aggregate is considered as a product instead of a waste), as well as the purchaser receiving proper aggregates compliant with relevant European Standards.

A new edition of the Aggregates Quality Protocol is due for publication in 2013, having completed its five year review.

Box 2 Quality protocols for other aggregates

Secondary aggregate materials such as steel slag, incinerator bottom ash aggregates and aggregates derived from coal power generation are/will be covered by their own individual quality protocols. Air-cooled blastfurnace slag has its own arrangements as it is considered to be a by-product rather than a waste. This is an active and developing area. The Environment Agency website gives further details of the current status of these Quality Protocols^[8].

2.3 Why specify or use recycled or secondary aggregates?

Some of the main advantages of using recycled and secondary aggregates are:

- Reduced waste disposal costs: Avoidance of landfill tax/gate fees if site materials can be processed into aggregates, leading to a reduction in overall cost.
- Gain materials credits in the Code for Sustainable Homes^[9]. The Code for Sustainable Homes gives credits (under Category 3, Materials) for using recycled and secondary materials in a development. This includes the foundations and substructure (including sub-base materials).
- Reduce transport/haulage costs: Materials can be properly processed to meet end user requirements and recycled on site instead of removing them from the site and importing material to the site.
- Reduce construction materials costs: Recycled and secondary aggregates can be cheaper than primary aggregates. However, this is not invariably the case as additional processing (such as screening/washing) may be required.
- Competitive advantage/improved tender and contract negotiations due to positive environmental credentials of recycled materials: in 2003, the Government's Sustainable Procurement Group recommended setting requirements for recycled content in public procurement of construction projects, and a target was set by WRAP and the Office of Government Commerce. In 2004, the Government's Sustainable Buildings Task Group recommended the same requirement to be included in the Building Regulations. To date the latter has not been formally introduced but many public clients are already implementing the above recommendations by setting recycled content requirements for a range of construction projects, eg Glasgow City Council (in all its major construction projects), Bristol and Newcastle City Council (in school PFIs), Dundee City Council (in waste management infrastructure).

There are a number of potential environmental, societal and business benefits in using recycled and secondary aggregates. These are summarised in Table 1.

Table 1 A summary of the potential benefits of using recycled and secondary aggregates

Environmental and social benefits	Business benefits
<ul style="list-style-type: none"> ■ Diversion of waste from landfill ■ Reduced number of lorry movements (through use of site-won materials instead of primary aggregates) ■ Potentially lower CO₂ emissions ■ Reduced overall environmental impacts (if transport distances are low) 	<ul style="list-style-type: none"> ■ Gain materials credits in the Code for Sustainable Homes ■ Reduced transport/haulage costs ■ Reduced waste disposal costs ■ Competitive advantage/improved tender and contract negotiations

The main current limitations on the use of recycled and secondary aggregates are:

- Limited local availability for certain applications and of certain materials. For example, recycled concrete aggregate, which mainly comprises crushed concrete, is not widely available in large volumes. Availability is a key issue. Sufficient of such material needs to be available to complete the whole job and at the time that the job is taking place.
- Technical limitations on the proportion of certain types of recycled and secondary aggregates that can be used in, for example ready-mixed concrete, and on the grades of concretes in which these are permitted. This stems mainly from the wide range of potential brick types in RA (which is primarily crushed masonry) and their effects on properties of the fresh and hardened concrete.
- The use of such non-primary aggregates does not invariably represent the most sustainable option. Issues to consider include transport distances and any need to modify concrete mix proportions and the effects of this on CO₂ emissions.

Further information on the benefits and drivers of using recycled and secondary aggregates are given on WRAP's AggRegain website^[10].

2.4 Recycled and secondary aggregates, environmental benefits and CO₂ emissions

Aggregates themselves are relatively low embodied CO₂ materials (approximately 4 kg per tonne)^[11,12] and broadly similar operations are used to process and screen both natural and recycled/secondary aggregates. Therefore there is a risk that the embodied CO₂ can be increased significantly by long transport distances. This is of particular importance when specifying recycled and secondary aggregates. One of the risks of being too prescriptive in specifications is that it may result in aggregates being transported over significant distances and thus increase the embodied CO₂ of the concrete while trying to reduce the primary resource use.

As a rough guide, if the haul length by road for the recycled or secondary aggregates is greater than that for conventional aggregates, then there will be an increased embodied CO₂ associated with the recycled or secondary aggregates. This will counteract the environmental benefit in the reduction in extraction of primary aggregates. Detailed tools and guidance for calculating the CO₂ impacts of various aggregate sources and circumstances can be downloaded from the websites of WRAP and the MPA^[13,14].

The main environmental benefits in using recycled and secondary aggregates are generally associated with diversion of material from landfill, reduction in the amount of primary minerals extraction and, in some situations, reduced vehicle movements.

2.5 Pre-cast concrete products with recycled content

Factory-made concrete and related products such as pre-cast concrete blocks, pavers, concrete roof tiles etc, commonly contain recycled or secondary aggregates or other recycled materials. Websites such as the *Green Guide to Specification*^[15] and the supplier directory on the WRAP website^[16] can assist potential purchasers in finding manufacturers, suppliers and products. As these products include bulk items such as beams, lintels, block paving and roof tiles, there is a potential to make residential construction products more sustainable through including these products in residential developments.

2.6 Sources and availability of recycled and secondary aggregates

2.6.1 Recycled aggregates (from the construction and demolition recycling industries)

The most widely used types of recycled aggregates in the UK (in tonnage terms) comprise materials derived from mixed construction and demolition waste (ie masonry/concrete), followed by asphalt plantings (recycled asphalt). Data from WRAP (unpublished) indicates that there are (as at 2011) nearly 600 crushing plants processing construction, demolition and excavation waste throughout the UK. Contact details of suppliers on a regional basis are available via WRAP's AggRegain website^[17]. There are many large recycled processing operations which produce European Standard-compliant recycled aggregate without the need to wash. A range of recycled products (such as building sand, single-sized coarse aggregate, and Type 1 material as defined in Series 0800 of the *Specification for Highway Works*^[18]) are available.

There are two main approaches to producing recycled aggregates: in-situ (at the site of the arisings), or ex-situ at a central processing plant. Unless the Aggregates Quality Protocol (Box 1) has been applied, waste transfer costs could be associated with handling an aggregate material which does not comply with the appropriate European Standard for its application. The material also remains a waste according to waste legislation.

A new generation of central combined washing plants and crushing/screening facilities (for processing demolition and excavation spoil) also exist at a number of locations. For commercial reasons, the main output is generally a range of recycled aggregate products (aimed at such uses as unbound fills, sub-base and pipe bedding) rather than just a segregated recycled concrete aggregate (RCA). BRE consultations indicate that there are approximately 20 to 30 washing plants UK wide (in 2011) (see Box 3).

Box 3 Aggregate washing plants in the UK

A number of plants have been installed to process inert construction and demolition waste to meet the increasing demand for quality recycled aggregate, while reducing the pressure on landfill.

Inert construction, demolition and excavation waste is crushed and screened before being fed into the washing plant. A sorting screen removes any unwanted oversized waste, including plastic and wood. The material then passes to a log washer and screener to clean, size and de-water the aggregates. Modern washing plants also have a water recovery system that allows the recycling of water. Silt recovered from the process is compacted using a plate press into silt cakes, which are used in blends of soils and composts for use in site restoration^[19].

One particular example in southern England crushes and screens inert construction and demolition waste which is then fed into the washing plant. The plant allows an optimum throughput of approximately 50 tonnes per hour with an annual output of 65,000 tonnes of sand and aggregate. Recycled aggregates produced at the plant, include a range of single site material including recycled aggregate suitable for use in concrete.

2.6.2 Other aggregates from non-primary sources (secondary aggregates)

Secondary aggregates (using the term in its strictest sense as defined in section 2.1), represent a much smaller resource than recycled aggregates. The availability of secondary aggregates across the UK varies significantly depending largely on the geographical source of production. For instance, colliery spoil is available in former coal mining areas and china clay waste in Devon and Cornwall. Supplies of IBAA are relatively small in tonnage terms at present but are expected to increase strongly as more municipal waste incinerators come on stream. In total, however, secondary aggregates form a relatively small proportion (approximately 3%) of the UK aggregates supply, with recycled aggregates at approximately 21% of total UK aggregate supply^[20].

2.7 Excavated soil, related materials and reuse of foundations

2.7.1 Excavated soil and related materials

Excavated soils are not strictly speaking, aggregates, but are worthy of a brief mention. In general, both contaminated and uncontaminated materials that are excavated from development sites are considered to be waste and therefore subject to regulatory controls. Use of a Code of Practice (CoP), such as the CL:AIRE Development Industry, CoP^[21] can provide an alternative to environmental permits or waste exemptions. The Environment Agency, which regulates the management of waste materials, may deem that excavation materials are no longer waste where this or a similar CoP is correctly applied. The CL:AIRE CoP currently allows reuse of contaminated or uncontaminated materials on the site of production and between sites within defined cluster projects. It also allows for the direct transfer and reuse of clean, naturally occurring soil materials between sites. The scope of the CoP excludes excavated infrastructure material such as pipework and storage tanks (which may potentially be contaminated). However, excavated infrastructure such as road bases, car parking areas etc, can be reused under the CoP on the site of origin and on receiver sites within a cluster. If fully complied with, the Aggregates Quality Protocol^[7] (Box 1), allows for inert materials to be used at any site, including those currently not within the scope of the CoP.

2.7.2 Reuse of existing foundations

Redevelopment and regeneration of urban areas have left a legacy of old foundations, congested underground space and archaeological artefacts. This legacy can compromise new developments. Reusing existing foundations can provide environmentally sustainable foundations for future developments and there are a range of economic, technical and environmental drivers. The project Reuse of Foundations for Urban Sites (RuFUS), partly funded by the EU, has researched the topic and developed guidance on foundation reuse. It gives advice on how to address risk and choose an appropriate foundation option^[22]. It also provides technical advice on investigation, design and construction using reused foundations.

3 Applications for recycled and secondary aggregates in residential construction



3.1 Introduction

The main applications for recycled and secondary aggregates being considered in this technical guidance are:

- aggregates for vibro stone columns (for ground improvement on sites for residential development)
- fill beneath buildings
- hardcore
- pipe bedding and surrounding material
- drainage (stormwater drains and soakaways)
- coarse aggregates in some types of concrete for domestic use (including reinforced)
- private drives or pathway construction (asphalt, concrete or sub-base)
- bedding/laying sand for paving etc
- hydraulically bound mixtures (for pathways and hard standing).

Table 2a and 2b gives examples of aggregate materials that can be used in particular applications, the product types in which they can be used and specific limitations (if any). Note that the materials mentioned are only examples and a wider range of materials may also be suitable. The WRAP AggRegain website^[17] also gives further details. Volume 7 of the Highways Agency – *Design Manual for Roads and Bridges: HD35/04 Conservation and the Use of Secondary and Recycled Materials*^[23] is a useful summary document which describes provisions for the use of secondary and recycled materials in applications such as sub-base,

pipe bedding, fill and concrete, listing the permitted aggregate materials in these applications against the relevant Series document of the *Specification for Highway Works*^[18].

Table 2a Summary of potential uses of recycled and secondary aggregate in residential construction (BRE recommendations)

Application	Examples of recycled or secondary aggregate materials that can be used alone or in combination	Proportion of recycled aggregate which can be achieved	Sources of aggregate which can be unsuitable	Examples of material type or concrete product where recycled and secondary aggregates can be used	Any practical issues/limitations
Unbound aggregates					
Hardcore	Wide range including recycled concrete aggregate, recycled aggregate	100%	See Appendix B	See Appendix B	See Appendix B
Fill beneath buildings/ sub-structures	Wide range including air cooled blastfurnace slag, Burnt colliery spoil, recycled concrete aggregate, recycled aggregate	100%	Old bank slags	Class 1A, 1B and 1C material (granular fill)	Risk of volume instability of old bank slags
Pipe bedding and surround	Recycled concrete aggregate, recycled aggregate, crushed glass	100%	Unburnt colliery spoil, burnt colliery spoil	Types B, F, N, S, T and Z, SMF (for bedding). Types S, T and Z (for surround)	Single-sized material that supports and will not damage the pipe are most suitable
Stormwater drains and soakaways	Clean recycled aggregate or crushed glass	100%	–	Type A, B and C	Blastfurnace slag may not be appropriate in some special situations that are poorly drained- see Environment Agency/British Aggregate Construction Materials Industries (now the Mineral Products Association [MPA]) guidance ^[24]
Private drives or pathway construction (sub-base)	Most recycled aggregates suitable	Up to 100% (with some exclusions)	–	Type 1. Type 2	–
Vibro stone columns	Recycled concrete aggregate, reclaimed rail ballast	100%	Most recycled aggregates	See guidance in BRE Report 391 <i>Specifying Vibro Stone Columns</i> ^[25]	Grading, particle size and stability. As vibro stone columns are unbound, vertical permeable aggregate columns, the aggregates may need to be analysed for contaminants which may pose a risk to water, soil and human health.
Bedding/ laying sand for paving etc	Glass sand. Graded demolition fines	100%	–	Free draining gritty sand	–

Table 2b Summary of potential uses of recycled and secondary aggregate in residential construction (BRE recommendations)

Application	Examples of recycled or secondary aggregate materials that can be used alone or in combination	Proportion of recycled aggregate which can be achieved	Sources of aggregate which can be unsuitable	Examples of material type or concrete product where recycled and secondary aggregates can be used	Any practical issues/limitations
Bound aggregates					
Coarse aggregates in some types of concrete for domestic use (floors, foundations including reinforced)	Recycled concrete aggregate, recycled aggregate (in some concrete types)*. China clay stent, slate, other [§] .	Up to 20% or 100% of coarse aggregate (depending on concrete type)	Incinerator bottom ash aggregates [‡] . Steel slag [†] .	GEN1, ST2 (shallow foundations). ST3, GEN2 (internal floors). Concretes for insulated concrete formwork construction.	Limited availability of RCA. RCA and RA are not permitted in higher strength grades. RCA or RA can increase water demand of the mix. The shape of slate particles can lead to problems with workability.
Private drives or pathway construction (asphalt base)	Wide range including incinerator bottom ash aggregates, reclaimed asphalt, blastfurnace slag and steel slag (well weathered)	Up to 100%	–	Hot rolled asphalt	–
Hydraulically bound mixtures (for pathways and hard standing)	Very wide range including China clay sand, recycled concrete aggregate, incinerator bottom ash aggregates, steel slag fines	100% best practice	–	Base, sub-base, or bound fill	–
<p>* Recycled aggregate (RA) is not permitted in standard (ST-type) designated mixes (BS 8500-2¹).</p> <p>† Steel slag can be produced by the basic oxygen process or electric arc furnace process. Both electric arc furnace and basic oxygen process slag can be dimensionally unstable if not properly weathered/processed. Various processed slags such as air-cooled phosphorus slag, basic oxygen process slag, electric arc furnace slag, air-cooled blastfurnace slag and zinc slag are appropriate materials for applications including hydraulically bound mixtures.</p> <p>§ There are some references to the successful use of steel slag as aggregate in concrete²⁶ but there is a very high risk of dimensional instability and pop-outs if the material is not appropriately processed.</p> <p>‡ Incinerator bottom ash aggregates may contain metallic aluminium, which could lead to surface pop-outs or hydrogen formation when used in concrete.</p>					
Other general notes					
1 Recycled aggregate (where denoted RA) is predominantly crushed brick; recycled concrete aggregate (where denoted RCA) is predominantly crushed concrete.					
2 The types of suitable aggregate materials above are only examples and a wider range of materials may be suitable. The WRAP AggRegain website gives further details ¹⁷ .					

A few recycled and secondary aggregates that meet the relevant quality protocols are, nevertheless, not well suited to particular end uses due to issues including shape, grading and composition. More importantly, some materials sold over many years as recycled aggregates may be highly unsuitable for certain applications. The difficulties are generally due to some form of dimensional instability or the potential for sulfate attack on adjacent construction. Examples are:

- mixed slags from old slag banks
- demolition rubble containing gypsum (eg plaster)
- colliery spoil with high levels of sulfates
- incinerator bottom ash with high levels of sulfates.

Common features of construction situations where there have been problems (in BRE's experience) are that materials have been used that are highly variable/poorly understood in relation to the end use, poorly documented and/or have limited quality assurance processes in place.

3.2 Unbound aggregates

In civil engineering terminology, material used for applications including hardcore and pipe bedding, may be termed, according to context, an unbound material or an unbound mixture made up of aggregates. Fill and hardcore are two of the most common uses for recycled and secondary aggregates in residential construction.

3.2.1 Selection of fill

Engineered fills are granular or cohesive materials (see Box 4) that are used to fill depressions or holes in the ground or to artificially change the grade or elevation of a site. Such fill may either be site-derived material or it may be imported to the site. The various Series' and clauses of the Highways Agency *Specification for Highways Works* give further details. Series 0600 (Earthworks)^[27] gives details on construction of fills (clause 608), fill to structures (clause 610) and compaction of fill (clause 612). Clause 601 gives details of materials which are suitable and unsuitable for use in fill and limitations in their use.

Box 4 Recycled and secondary aggregates as granular or cohesive fills

There are basic differences in behaviour between coarse granular soils and fine cohesive soils^[28]. Coarse soils tend to have high shear strength and permeability whereas fine soils generally have lower strength and permeability. The percentage of silt and clay size particles is important as when this is high (>35%), the soil will cease to behave as coarse soil. Cohesive fills principally comprise materials that give properties and performance similar to that of a fine cohesive soil. Granular fills comprise mainly material of significant particle size, will readily appear to consist of easily distinguishable separate particles and would be expected to behave similar to a coarse soil.

Examples of recycled and secondary aggregates that may be suitable for granular fills (alone or in combination) include: blastfurnace and zinc slags, burnt colliery spoil, china clay sand and stent, foundry sand, pulverised fuel ash, reclaimed asphalt, recycled concrete aggregate, recycled aggregate, recycled glass, slate aggregate, and spent oil shale.

3.2.2 Dealing with existing fill and made ground on sites for development

Sites selected for residential development may include existing filled areas. The term 'made ground' describes ground that has been formed by material deposited by man. Made ground may be composed of natural soil and rock or may be formed from industrial, chemical, mining, dredging, building, commercial and domestic wastes. Fill commonly encountered on development sites in the UK includes opencast mining backfill, colliery spoil, pulverised fuel ash (pfa), industrial and chemical wastes including iron and steel slags, building and demolition wastes and domestic refuse. Many clay and gravel pits, quarries and disused docks have been infilled. Hydraulically deposited fill may also be encountered. The term landfill is often used to describe domestic refuse^[29].

The development of such filled sites can present a wide variety of problems, the most serious of which are generally associated with either a lack of ability of the fill to support building construction without excessive settlement, or the presence in the fill of materials which could be hazardous to health or harmful to the environment or the building.

3.2.3 Aggregates for vibro stone columns

The two critical issues that apply to any aggregates used to form vibro stone columns are its grading, strength and stability. Several types of recycled or secondary aggregates can be suitable. Appendix B2 of this guide gives further details.

3.2.4 Hardcore

Hardcore is a commonly used construction term used to denote engineered infill material that is placed within the confines of a building foundation (after removal of any unsuitable ground layers) in order to support a ground-bearing floor slab. Materials for hardcore should be granular, and drain and compact readily, as well as being chemically inert, physically stable and not affected by water. An excellent and very practical guide is provided by Parts 1 and 2 of BRE Digest DG 522 *Hardcore for Supporting Ground Floors of Buildings*^[30, 31]. Part 1 of DG 522 deals with selecting and specifying materials for hardcore and limitations in their use; Part 2 deals with placing hardcore and draws lessons about past uses of 'problem' materials as fill and hardcore.

Cautionary note: The term 'hardcore' is restricted here to denoting material used as engineered fill for supporting ground floor slabs. The specific usage has long been employed by professionals engaged in residential construction and is endorsed by such usage in Building Regulations documents. However, you need to be aware that the term also has a broader lay usage that denotes a randomly sized crushed material of poorly understood composition which has not been produced to the relevant BS EN aggregates standard, (which for unbound applications is BS EN 13242^[32] and the corresponding National Annex PD 6682-6^[33]). Such material will not meet the requirements of the Aggregates Quality Protocol^[7] and, hence, material sold under the product description hardcore may still be a waste.

Selection of appropriate material for hardcore

Part 1 of DG 522^[30] sets out a framework for selection of materials for hardcore. Material for use as hardcore in buildings needs to provide stable and adequately strong support for the ground floor slab and any superimposed loads during the working life of the building. Usually it will not be possible to rectify any post-construction problem originating in the hardcore without major disruption and cost. While sub-base material intended for highways generally has all the properties needed for hardcore, the Highways Agency specifications allow for it to be less dimensionally stable and more chemically active than is appropriate for use within the rigid confines of a building foundation and floor slab.

The main essential characteristics of material to be used as hardcore for buildings as specified in DG 522 Part 1 are that it is:

- Straightforward to handle, place and compact within the confines of a building foundation.
- Capable of supporting the floor and superimposed loads without compression.
- Dimensionally stable after placement (it must not be prone to expansion or compression).
- Physically unaffected by change in water content when in place.
- Biologically inert, ie free from organic matter that might decay or support fungal growth.
- Chemically inert, ie free of any substance that might react within the hardcore material causing volume change, or that might attack adjacent construction elements.

Appendix B1 of this guide gives further guidance on the selection of appropriate material for hardcore.

It should be noted that there is not a standard specification for hardcore, although in most respects, Type 1 or Type 2 material complying with Series 0800 of the *Specification for Highway Works*^[18], (with appropriate additional safeguards on issues such as sulfate content/dimensional stability) may be suitable.



Figure 2 Hardcore being compacted
(© Bellway Homes East Midlands)



Figure 3 Hardcore in place and being blinded with sand
(© Bellway Homes East Midlands)

3.2.5 Pipe bedding and surrounding material

Unbound aggregates used as bedding to pipes provide a supporting surface which will not damage the pipe, membrane or other material placed above the pipe and to allow the pipe to be manoeuvred and placed. Natural, manufactured or recycled granular materials (such as RA, RCA or recycled glass) can all be suitable. Materials are crushed and screened into single sizes, which are then recombined into an unbound material (typically below 14 mm maximum size) with the appropriate size grading for the end application. Different gradings are required depending on the pipe diameter (eg Type B, Type N, etc as defined in Series 0500 in Volume 1 of the *Specification for Highway Works*^[34]). Pipe bedding is also referenced in Clause 503. The latter also includes filter media materials (Clause 505). Instead of unbound aggregates, pipe bedding can also utilise ST2 or ST4 concretes, which can in turn contain RAs^[3], (although RA aggregate is not permitted in ST (standard mix) concretes).

3.2.6 Drainage (stormwater drains and soakaways)

Soakaways must not have the potential to pollute groundwaters. In suitable ground they can be used for any application, from small single storey extensions through to complete buildings and even to entire estates, although in the latter case, they should be part of a full SUDS scheme. Soakaways can be filled with rubble or single size material (eg 20 to 10 mm; 10 to 5 mm) and clean recycled aggregate (ie without fines or dust), is generally suitable. Joint guidelines issued by the Environment Agency and British Aggregate Construction Materials Industry (BACMI, now the Mineral Products Association [MPA])^[24] give specific guidance to avoid leaching of harmful sulfur species and other compounds into the water environment. These guidelines state for example, that unbound blastfurnace slag should not be used below the water table or in waterlogged or poorly drained areas.

3.2.7 Green roofs

Green roofs can also use recycled and secondary materials. The term brown roof or eco-roof is often used in conservation circles to refer to the mitigation for the loss of brownfield land. Brown roofs use a substrate material, laid down on a flat roof and allowed to colonise naturally. Often, crushed bricks and recycled aggregates from the previous construction of the building are left to colonise naturally or are deliberately seeded^[35].

3.3 Aggregates for use in concrete

3.3.1 Introduction

Recycled and secondary aggregates can be used very successfully as a proportion of the coarse aggregate fraction in concrete. The current British and European Standards (BS EN 12620^[6] and BS EN 13055-1^[36]) and accompanying national guidance documents PD 6682-1^[37] and PD 6682-4^[38], that apply to aggregates for concrete, do not discriminate against non-primary aggregates.

The most frequent application of recycled and secondary aggregates in concrete involves the use of specific types of recycled aggregates; coarse RA or recycled concrete aggregate (RCA) which are closely defined in the concrete standard BS 8500-2^[11] (Appendix F of this guide gives further details).

3.3.2 Limitations on the use of recycled aggregates in concrete

The UK currently has limited available material to support the widespread use of recycled aggregates in concrete, however it is likely that in the coming years the use of recycled and secondary aggregates will become more common in concrete. One of the biggest practical problems with using more RCA and RA in concrete is their limited availability at the right time and in the right place. Thus concrete suppliers may not always have the materials at their plants when a new project starts. The main alternative to using RCA and RA is, of course, natural aggregate and these are still relatively low cost materials although, due to the Aggregate Levy, the cost has increased significantly in recent years. If RCA and RA have to be transported a significant distance from the place of production to the place of use, both the cost and environmental benefits may become more questionable. Appendix F gives further general and practical advice on the use of recycled and secondary aggregates in concrete.

3.3.3 The use of other recycled and secondary aggregates in concrete

In respect of application of European Standards, there is no reason why any aggregates (other than RA and RCA) cannot be used in concrete provided they meet the requirements of BS EN 12620^[6] or BS EN 13055-1^[36] and the recommendations within PD 6682-1^[37] and PD 6682-4^[38]. Examples include:

- china clay stent (coarse)
- crushed air-cooled blastfurnace slag (coarse, lightweight)
- china clay sand (fine)
- slate (in certain concretes)
- foundry sand (in certain concretes).

Crushed glass can perform satisfactorily as an aggregate in concrete but special attention needs to be given to mitigating the risk of expansion due to alkali silica reaction by, for example, the use of cement replacement materials and control of the maximum aggregate size.

Some of the aggregates listed above have been commonly used in prestigious projects such as the London 2012 Olympics development due to their availability and excellent properties for use in concrete mixes. However, the main difficulty for use in concrete can be in sourcing these materials as they comprise a relatively small proportion of the total aggregate supply.

3.4 Aggregates for private drives and paving

This section focuses on the application of recycled and secondary aggregates in drives, paving and paths (in unbound and bound applications). Further details relevant to concrete drives and paving are also available in Appendix F (aggregates for use in concrete).

3.4.1 Concrete (rigid paving)

For the construction of concrete drives for housing developments, PAV1 (as per Series 1000 of the *Specification for Highway Works*^[39] with a 75 mm slump (or 'S' consistence class) is generally suitable. A downloadable reference document gives a design specification^[40] making provision for the use of certain recycled and secondary aggregates.

Recycled and secondary aggregates can also be used at lower levels within the construction of concrete drives (eg sub-base). Information on the choice of recycled and secondary aggregates appropriate for use in sub-base for concrete drive construction is given in the following section on asphalt. Guidance on formulating sub-base for domestic drives based on crushed brick or masonry is given in Appendix B3.

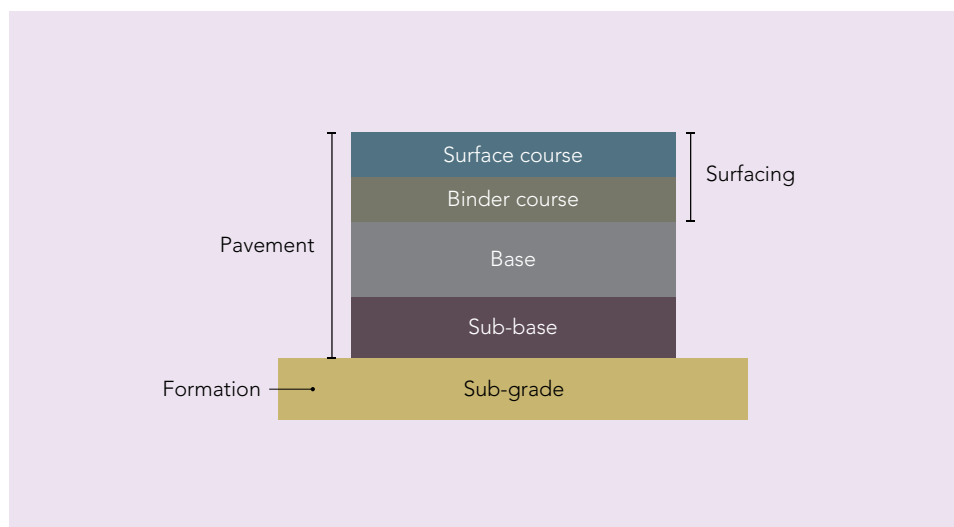


Figure 4 Schematic diagram of typical pavement design^[41]

3.4.2 Asphalt (flexible paving)

The document *Construction and Surfacing of Parking Areas Including Private Drives* published by the Mineral Products Association^[41] gives specifications for the structure of the pavement or drive. There are opportunities for recycled and secondary aggregates in the following applications:

- **Base:** *Specification for Highway Works Series 0800*^[18] for unbound aggregates allows for the use of a range of recycled and secondary aggregates in the base. Examples include blastfurnace slag and zinc slag, china clay sand and stent, foundry sand, incinerator bottom ash aggregate, pfa, reclaimed asphalt (up to 50%), RCA, RA, recycled glass, slate aggregate and steel slag.
- **Sub-base:** Suitable materials are Types 1 and 2 unbound mixtures or other locally available materials of known satisfactory quality such as crusher run and quarry scalplings. Suitable (and unsuitable) recycled and secondary aggregates are listed in Appendix C.
- **Sub-grade:** Fill or sub-base material can be used to shape to the required falls or to replace any weak areas.

3.4.3 Flexible pre-cast block paving

The bedding sand (more correctly known as laying course) for flexible pre-cast block paving is generally free-draining gritty sand that does not retain water. Concreting sand is suitable for use as laying sand, Type 0/4 (MP) Gf 85 fine aggregate to BS EN 12620:2002+A1:2008^[6] is suitable although some other materials (such as crushed rock fines) can be used where suitable sand is not available.

Natural sources are most commonly used. Recycled materials (eg glass sand) can be obtained although they are not widely available. The physical properties of soft sands make them unsuitable for use as unbound bedding sand. The pre-cast pavers themselves may also incorporate recycled and secondary aggregates (see supplier directories on the WRAP website^[16] and National Green Specification^[42] for further details of products).



Figure 5 Bedding sand made from crushed glass

3.5 Unbound material for pervious paving

The use of pervious paving is a key technique in SUDS for surface water management and source control of the quantity and quality of run-off. Surface water is infiltrated through the surface and into the underlying construction layers where water is stored prior to infiltration to the ground. Pervious surfaces are often used for pavements, walk paths, driveways and car parks.

If aggregates are used as the sub-base material below the pervious paving, these tend to be in contact with water, which could have an impact on the durability and strength of the aggregates when saturated. To maximise the performance of the aggregate particles, they should be rough and angular; crushed concrete or air-cooled granulated blastfurnace slag would be suitable. Sand and gravel with rounded particles should not be used. For guidance on pavement design see CIRIA report *Source Control Using Constructed Pervious Surfaces C582*^[43].

3.6 Hydraulically bound mixtures

Hydraulically bound mixtures (HBM) are a class of mixtures of aggregates and binders that set and harden by hydraulic reaction. They include cement stabilised material (cement bound mixtures ie mixtures based on the fast setting and hardening characteristics of cement). They also include hydraulically bound mixtures based on slow setting and hardening binders made from industrial by-products such as pfa and blastfurnace slag. Certain recycled and secondary aggregates are well suited for use in the HBM and their use offers some additional cost and sustainability benefits. HBM are most commonly adopted in major highway construction but also have potential to be used in a range of paving and non-paving applications. HBM construction is well known and versatile in terms of availability of plant and materials. Some HBM mixtures allow the reuse of materials available on site (eg soil, demolition wastes) with savings on imported primary material (avoiding the Aggregates Levy) and disposal costs.

WRAP provides design guidance to enable the specification and use of HBM in a range of applications^[44]. Specifically the guidance covers the use of HBM for minor roads, such as residential and commercial roads, and paved areas such as car parks for mixed retail, residential and leisure developments, hard-standing for commercial vehicles, leisure trails, wheelchair access paths or other paved areas. The WRAP guidance, which has a particular focus on design, will be of interest to developers, contractors, and civil engineering consultancy practices. Table 3 gives examples of the recycled and secondary aggregates that can be used in HBM, where the specification allows.

Table 3 Examples of recycled and secondary aggregates that may be suitable (alone or in combination) for use in hydraulically bound mixtures

China clay sand, recycled concrete aggregates, air-cooled blastfurnace slag, granulated blastfurnace slag*, burnt colliery spoil, pulverised fuel ash*, spent oil shale, recycled asphalt, other road arisings, slate aggregate, incinerator bottom ash aggregates
Basic oxygen steel slag (BOS)(including fines) [†] , electric arc furnace slag (EAF) (including fines) [†]
Air-cooled phosphorus slag
* Granulated blastfurnace slag (GBS is a sand-like material) can be used as 'aggregate' or as part of the binder
[†] It is possible that the materials listed may produce, through physical or chemical unsoundness, mixtures with volume stability problems. This will need checking during laboratory mixture design procedures to confirm that the slag has been properly processed, stored and tested prior to sale.

4 Selected guidance, what to order, lessons from experience and case studies



4.1 Selected guidance documents, codes and standards

Sections 4.1.1 to 4.1.3 provide a detailed overview of the main guidance documents, codes and standards published by BSI, Highways Agency, WRAP and NHBC that apply to recycled and secondary aggregates. Table 4 lists the main applications for recycled and secondary aggregates and the main guidance documents that apply to each application.

4.1.1 Codes, standards and other guidance

The key guidance documents, codes and standards relevant to aggregates and their applications in construction are listed below:

- BS EN 13285 *Unbound Mixtures – Specification*^[45].
- BS EN 13242 *Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction*^[32].
- The Highways Agency *Specification for Highway Works* generally facilitates the uptake of recovered materials such as reclaimed bituminous materials (Clause 902), unbound, hydraulically bound and other materials (0800 Series)^[18], aggregates for use in cement bound applications (1000 Series)^[39], drainage aggregates (0500 Series)^[34] and earthworks (0600 Series)^[27]. There are some limitations in the direct application of the *Specification for Highway Works* to building construction, which are discussed further in the sections above on unbound aggregates and in Part 1 of BRE Digest DG 522^[30].

- Aggregates for use in cement bound applications are included in Series 0800^[18], clauses 810 to 823. Materials used may include RA, crushed concrete, blastfurnace slag and pfa. There are some restrictions on the sourcing of such aggregates due to quality compliance and conformity requirements.
- Drainage aggregates in the 0500 Series (see clause 503). Aggregates for pipe bedding, surround to pipes, trench backfill and filter drains, include the use of RA and RCA within quality and conformity requirements.
- BS 8500-1 *Concrete. Complementary British Standard to BS EN 206-1. Method of Specifying and Guidance for the Specifier*^[3]. The specifier is offered five approaches to the specification of concrete, with the Standard describing the correct way of compiling specifications for designated, designed, prescribed, standardised prescribed and proprietary concretes. This part of BS 8500 also gives detailed guidance for the specifier, including advice on exposure classes, aggregate classes, presented as a series of tables with accompanying explanatory text. BS 8500-1 has been used by the ready-mixed concrete industry since December 2003 (replacing BS 5328). It was updated in November 2006.
- BS 8500-2 *Concrete. Complementary British Standard to BS EN 206-1*^[11]. *Specification for Constituent Materials and Concrete*. This part of BS 8500 specifies a number of basic requirements for concrete and its constituent materials, and gives specific requirements relating to the types of concrete listed in BS 8500-1. It also specifies requirements relating to delivery, conformity testing, production control and transport.
- UK national guidance document PD 6682-1:2009 *Aggregates for Concrete. Guidance on the Use of BS EN 12620*^[37] and EN 12620 *Aggregates for Concrete*^[6].
- NHBC Standards Parts 2 (Materials)^[46], Part 4 (Foundations)^[47], Part 5 (Substructure and ground floors)^[48] and Part 9 (External works)^[49].

4.1.2 Quality protocols

The WRAP *Quality Protocol for Aggregates from Inert Waste*^[71] (Aggregates Quality Protocol) is important for the reasons stated previously. Quality protocols in general apply not only to aggregates from inert waste, but also to industrial by-products including steel slag, IBAA and fly ash, quality protocols for which are still in development^[8].

4.1.3 NHBC Standards relevant to unbound aggregates

NHBC Standards require that fill materials used to support foundations and slabs, or as backfill to trenches, must be tested for suitability if they contain acid wastes, materials that contain sulfates, organic materials, or materials that may damage surrounding construction elements. They also require that fill, containing potentially expansive material, is not used below ground-bearing slabs. Written approval from NHBC is also required for use of colliery shale and certain other materials depending on the circumstances of use.

Table 4 Relevant documents and standards (arranged alphabetically by application)

Application	Reference document	Comments
Asphalt (for private drives)	Asphalt Applications 1: <i>Construction and Surfacing of Parking Areas Including Private Drives</i> ⁴¹⁾	Guide published by the Mineral Products Association (MPA). Includes guidance on recycled and secondary aggregates suitable for different construction layers in roads
Concrete	BS EN 206-1 <i>Concrete. Specification, Performance, Production and Conformity</i> ⁵⁰⁾	BS EN 206-1 specifies requirements for the constituent materials of concrete, properties of fresh and hardened concrete and verification of these properties, limitations for concrete composition, specification of concrete, delivery of fresh concrete, production control procedures and conformity criteria and evaluation of conformity
Concrete	BS 8500-1:2006 <i>Concrete. Complementary British Standard to BS EN 206-1. Method of Specifying and Guidance for the Specifier</i> ⁴³⁾	BS 8500-1 is intended for use by specifiers of concrete. The specifier is offered five approaches to the specification of concrete, with the standard describing the correct way of compiling specifications for designated, designed, prescribed, standardised prescribed and proprietary concretes. BS 8500-1 also gives detailed guidance for the specifier, including advice on exposure classes for durability, aggregate classes, intended working life and consistence, presented as a series of tables with accompanying explanatory text
Concrete	BS 8500-2:2006 <i>Concrete. Complementary British Standard to BS EN 206-1. Specification for Constituent Materials and Concrete</i> ⁴¹⁾	BS 8500-2 specifies a number of basic requirements for concrete and its constituent materials, and gives specific requirements relating to the types of concrete listed in BS 8500-1. It also specifies requirements relating to delivery, conformity testing, production control and transport
Concrete	PD 6682-1:2009 <i>Aggregates for Concrete. Guidance on the Use of BS EN 12620</i> ³⁷⁾	PD 6682-1 is the first point of reference in the UK for the application of EN 12620 (see below)
Concrete	BS EN 12620 <i>Aggregates for Concrete</i> ⁶⁾	Specifies the properties of aggregates and filler aggregates for use in concrete
Concrete (Private drives)	<i>Specification for Highway Works, Series 1000, Road Pavements – Concrete Materials</i> ³⁹⁾	Sets out detailed construction requirements for road pavements. Also includes details of strength classes of concrete and constituent materials suitable for pavement layers
Concrete (Private drives)	<i>Mix Design Specification for Low Strength Concretes Containing Recycled and Secondary Aggregates</i> ⁴⁰⁾	Leads the reader through specification and mix selection processes for concrete for use in applications such as footings and driveways
Drainage and soakaways	BS EN 13242 + A1:2007 <i>Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction</i> ³²⁾	Specifies the properties of aggregates for unbound materials for civil engineering work and road construction. Limits on these properties (and example specifications) for applications such as drainage layers are given in National Annex PD 6682-6 ³³⁾
Drainage and soakaways	<i>Specification for Highway Works, Series 0500 – Drainage and Service Ducts</i> ³⁴⁾	Specifies physical property requirements for aggregates (including recycled and secondary) for various applications. Clause 503 (bedding and pipe surround); Clause 505 (backfill for trenches or filter drains)
Fill	<i>Specification for Highway Works, Series 0600 – Earthworks</i> ²⁷⁾	Gives general guidance on materials that are acceptable (and unacceptable) for use in Earthworks Materials for use as fill above structural concrete foundations, fill to structures are specifically included
Hardcore for supporting ground floor slabs	BS EN 13285 <i>Unbound Mixtures – Specification</i> ⁴⁵⁾	Covers aggregates, mixtures, classification systems, particle size distribution, particle size measurement, composition, recycling and quality control
Hardcore for supporting ground floor slabs	BS EN 13242:2002+A1:2007 <i>Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction</i> ³²⁾	Specifies the properties of aggregates for unbound materials for civil engineering work and road construction. Limits on these properties for use as fill and sub-base, and example specifications, are given in the accompanying annex PD 6682-6 ³³⁾

Application	Reference document	Comments
Hardcore for supporting ground floor slabs	<i>Specification for Highway Works Series 0800, Road Pavements – Unbound, Cement and Other Hydraulically Bound Mixtures</i> ^{18]}	Specifies particle size grading requirements for Type 1, Type 2 and other unbound mixtures. Refers specifically to RA and RCA. Also includes compositional requirements and performance requirements (such as freeze thaw resistance and water absorption)
Hardcore for supporting ground floor slabs	BRE Digest DG 522 Part 1 <i>Hardcore for Supporting Ground Floors of Buildings: Selecting and Specifying Materials</i> ^{30]} . Part 2: <i>Placing Hardcore and the Legacy of Problem Materials</i> ^{31]} .	Provides guidance on selecting and placing material for use as hardcore in building construction. It takes account of recent standards for specifying aggregate materials for use as hardcore, ensuring that the material is both physically stable and chemically inert. In Part 1 candidate materials are reviewed, including recycled and secondary materials that are currently being promoted for use in construction as a sustainable option. Simplified recommendations for common situations are also given.
Hydraulically bound mixtures (HBM)	<i>Promoting the Use of Applications Incorporating Recycled and Secondary Aggregates in HBM</i> ^{44]}	WRAP document providing guidance on the costs, technical benefits, cases studies of successful use, durability etc of HBM containing recycled and secondary aggregates. The guidance is across a range of sectors covering both buildings and infrastructure. Case studies, illustrate the use of recycled and secondary aggregates in HBM in a range of applications
Hydraulically bound mixtures	<i>Specification for Highway Works Series 0800, Road Pavements – Unbound, Cement and Other Hydraulically Bound Mixtures</i> ^{18]}	Clauses 810 and 820 cover testing and the properties of aggregates suitable for use in HBM. Guidance on the constituents of different types of mixtures, aggregate particle size grading and compositional requirements performance requirements are also included)
Hydraulically bound mixtures	BS EN 13242 + A1:2007 <i>Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction</i> ^{32]}	Specifies the properties of aggregates for hydraulically bound materials for civil engineering work and road construction. Example specifications for cement bound materials are given in the accompanying annex PD 6682-6 ^{33]}
Pipe bedding	BS EN 13242 + A1:2007 <i>Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction</i> ^{32]}	Specifies the properties of aggregates for unbound materials for civil engineering work and road construction. Limits on these properties for use as pipe bedding, and example specifications, are given in the accompanying national annex PD 6682-6 ^{33]}
Pipe bedding	<i>Specification for Highway Works, Series 0500, Drainage and Service Ducts</i> ^{34]}	Specifies physical property requirements for aggregates (including recycled and secondary) for various applications including pipe bedding. Clause 503 (bedding and pipe surround)
Unbound	<i>Specification for Highway Works, Series 0800, Road Pavements – Unbound, Cement, and Other Hydraulically Bound Mixtures</i> ^{18]}	The principal UK guidance on unbound mixtures is provided by the 0800 Series

4.2 What is available and what to order

When ordering recycled or secondary aggregate products, you should ask for aggregates that are produced and supplied meeting the requirements of the Aggregates Quality Protocol for particular specific products and specifications (eg Type 1 sub-base, unbound material *Specification for Highway Works*). Examples are given in Table 5.

Table 5 Examples of common types of construction aggregates which may contain or be entirely made up from recycled and secondary aggregate products

Product	Applications	Relevant standards/specifications
Fines	Back fill for cable trenches over sub-base	<i>Specification for Highway Works Series 0500, Drainage and Service Ducts</i>
Sand	Bedding/laying sand	Grading requirements given in BS 7533-3:2005 <i>Code of Practice for Laying Precast Concrete Paving Blocks and Clay Pavers for Flexible Pavements</i> ⁵¹
Asphalt planings (also known as crushed tarmac planings)	Driveways, also bitumen bound materials (base, binder and surface courses), pipe bedding, Hydraulically bound mixtures, unbound mixtures for sub-base, embankments and fill	<i>Specification for Highway Works, Series 0500, 0600, 0700, 0800, 0900</i>
Earthworks Material Class 6F4	Granular fill (fine graded)	<i>Specification for Highway Works, Series 0600</i> ²⁷
Earthworks Material Class 6F5	Bulk (granular) fill	<i>Specification for Highway Works, Series 0600</i> ²⁷
Sub-base Type 1 (also known as DOT Type 1 or MOT Type 1)	Road or path construction, sub-base	<i>Specification for Highway Works, Series 0800</i> ¹⁸ , clauses 801 and 803
Sub-base Type 2 (also known as DOT Type 2 or MOT Type 2)	Road or path construction sub-base (placement conditions are more exacting than for Type 1)	<i>Specification for Highway Works, Series 0800</i> ¹⁸ clauses 801 and 804
Free-draining aggregate 5 to 20 mm	Land drainage, soakaways or backfill for larger pipes	<i>Specification for Highway Works, Series 0500</i> ³⁴
Free-draining aggregate 20 to 40 mm	Land drainage, soakaways or backfill for larger pipes	
Free-draining aggregate 40 to 75 mm	Land drainage, soakaways or backfill for larger pipes	
Notes		
1 All the products listed in Table 5 must be produced in accordance with the WRAP <i>Quality Protocol for Aggregates from Inert Wastes</i> ⁷¹ in order to provide reassurance of quality and performance and to meet waste management regulations (ie material classed as a product, not a waste)		
2 Suppliers are listed on WRAP AggRegain website http://aggregain.wrap.org.uk and searchable by postcode		
3 The specifier tool on WRAP's AggRegain website provides specimen contract clauses which can be downloaded		
4 The list of applications and products is not exhaustive and other products may be available		
5 For products marked in bold type, technical notes can be downloaded from WRAP's AggRegain specifier tool.		

4.3 Use of recycled and secondary aggregates: generic lessons learnt

4.3.1 Avoiding damage to buildings: some potential pitfalls

As with any aggregate, inappropriate use of recycled or secondary aggregates can lead to problems which can be difficult to rectify. Table C1 (in Appendix C) reviews some of the problems identified by BRE and the lessons learnt. Problems are not unique to these materials and significant performance issues can also be associated with certain natural (primary) aggregates. Examples include:

- pyrite rust surface staining or popouts associated with some gravels
- shrinkable aggregates (eg some basalts or greywackes)
- heave or chemical attack of concrete (due to pyrite bearing mudstones or shales).

Part 2 of BRE Digest DG 522³¹ gives further details.

Table C1 in Appendix C summarises some of the issues that may be encountered with recycled and secondary aggregates and how to avoid the pitfalls.

Several materials used in the past as hardcore beneath floor slabs have been the cause of substantial damage to buildings in the UK. The most commonly encountered ones have included blastfurnace slags from old slag banks^[52] and steel slag, both fresh and from old slag heaps. A common factor in the more severe cases of damage has been the availability of water to permeate through the hardcore, feeding an expansive chemical reaction that typically results in hydrated minerals that have greater volume than the source material. Such water may come from groundwater or from leaking fresh or foul water service pipes.

4.3.2 Other issues/general lessons

Quality assured materials (recycled and secondary aggregates or aggregates containing these) can be ordered (subject to availability) as viable alternatives to primary aggregates, with a number of advantages. However:

- It is often difficult for contractors to accumulate recycled aggregates from their own different local sites as waste legislation/the Aggregates Quality Protocol apply to, for example, transport and storage.
- The Aggregates Quality Protocol is rarely practical for small housing sites (if seeking to accumulate and reuse their own construction and demolition waste as aggregates).
- Current reuse of recycled and secondary materials on housing sites is typically low value and focused on avoiding waste disposal charges.

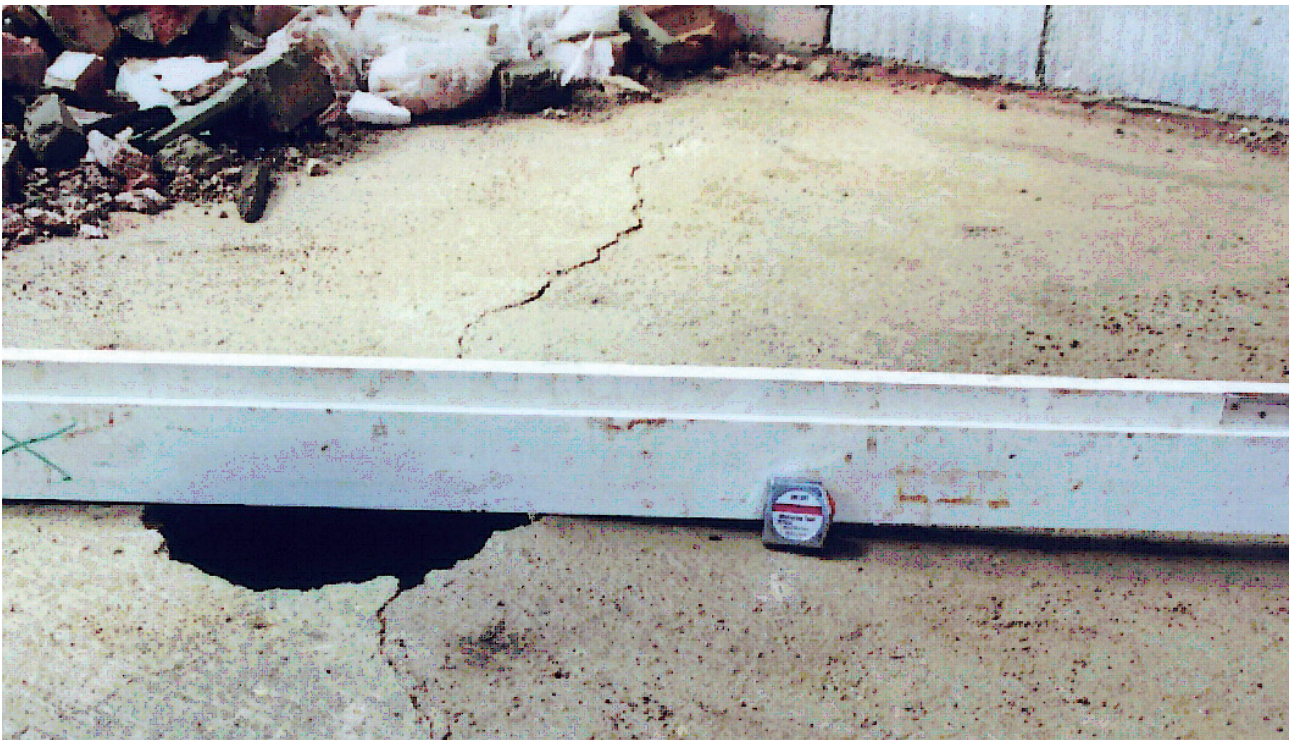


Figure 6 Sulfate attack to a concrete slab due to the use of brick rubble with gypsum plaster (© Ian Longworth)

4.4 Case studies

Case study A: Use of recycled aggregate in concrete for housing. Recycling in practice/supply chain partnerships

Many heavy building materials companies now work in partnership with local authorities to help meet their sustainability objectives and support their targets to increase recycling, reduce waste and minimise the use of primary materials. Dorset Works Organisation is a public/private partnership established by Dorset County Council and Hanson in 2003. It includes a number of specialist partners to ensure that requirements of the highways term service contract are met. Hanson provides a range of materials and contracting services to the partnership both directly and through the approved chain of additional partners, which includes Raymond Brown Group, New Milton Sand & Ballast, Skanska and Langley Civil Engineering. As part of this partnership, Hanson has successfully been using recycled aggregate from Raymond Brown's washing plant in its concrete plants in Dorset. This concrete has been supplied into several residential building projects.

Recycled aggregate in concrete

Hanson has been using the 4 to 20 mm recycled aggregate in concretes supplied to a number of Dorset Works Organisation projects throughout Dorset, including Ford Civil for Persimmon Homes in Shaftesbury, RM Mogridge in Shaftesbury and CJ Pitcher in Okeford. When using recycled aggregate in concrete, Hanson found that there was a need to increase the cementitious content of the concretes. Despite this, the overall carbon footprint was still lower than equivalent concrete made with 100% primary aggregates. All aggregates were tested and certified on behalf of the supplier by a UKAS (United Kingdom Accreditation Service) accredited testing house. All concretes supplied by Hanson with recycled aggregates conformed to the criteria in BS EN 206^[50] and BS 8500 for compressive strength. A fuller account of this case study is published^[53].

Supply chain partners

- Dorset County Council
- Raymond Brown Group
- New Milton Sand & Ballast
- Skanska
- Langley Civil Engineering
- Hanson.

Case study B: Victoria Wharf Housing development. The use of recycled aggregates on the Victoria Wharf Housing Development in Cardiff

Construction Project: Housing

Application: Piling mat and car park – capping layer

Product: Class 6F2 and 6F3

Material: Recycled concrete and recycled asphalt

Region: Wales

Date: 2004 to 2008

www.wrap.org.uk/downloads/Vic_Wharf_Case_Final_Version_v4.6e975fbf.2926.pdf.

Case study C: London Olympic Park

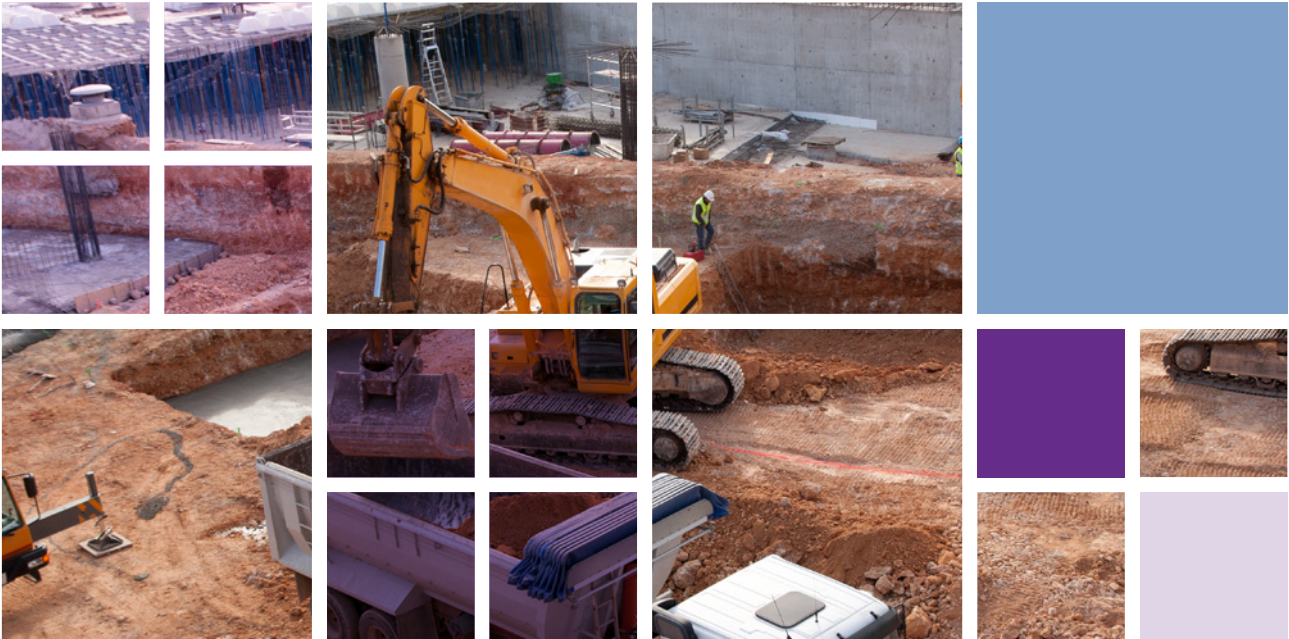
Recycled aggregates and cement replacements have been widely adopted in the overall London Olympics 2012 development. A major driver was to reprocess and reuse aggregate materials at the Olympic site or utilise in concrete through plants located near the site. Relevant learning legacy documents include the following:

Demolition Waste Management on the Olympic Park <http://learninglegacy.london2012.com/documents/pdfs/sustainability/15-demolition-waste-aw.pdf>

Construction Waste Management on the Olympic Park <http://learninglegacy.london2012.com/documents/pdfs/sustainability/16-const-waste-aw.pdf>

The Procurement and Use of Sustainable Concrete on the Olympic Park <http://learninglegacy.london2012.com/documents/pdfs/procurement-and-supply-chain-management/01-concrete-pscm.pdf>.

5 Conclusions and recommendations



High quality recycled and secondary aggregates are available on the UK market. The use of such aggregates in residential construction can offer a number of benefits including better resource efficiency, cost savings, additional materials credits in the Code for Sustainable Homes, reduced transport/haulage costs and competitive advantage/improved tender and contract negotiations.

The most widely used non-primary aggregates (in volume terms) are derived from recycled construction and demolition materials. The types available include a variety of 'fit-for-purpose' materials suitable for a wide range of bound and unbound aggregate applications in residential construction.

High quality recycled and secondary aggregates are produced in conformity with the Aggregates Quality Protocols. Compliance with these protocols provides reassurance that the material supplied meets the required environment and performance standards. It also ensures compliance with the national Waste Regulations, such that the material is classified as a product rather than a waste. Recycled aggregates not meeting the requirements of the Aggregates Quality Protocols for the production of aggregates from inert waste should be avoided. Some aggregate materials (certain secondary aggregates) have their own dedicated quality protocols.

The inappropriate use of recycled and secondary aggregates (and indeed, also of certain natural/primary aggregates), has occasionally led to problems with stability and appearance, resulting in costly remedial measures. The main examples, and approaches to avoiding them, are described in this guidance.

Appendix A

Useful websites

Business link

www.businesslink.gov.uk (select environment and efficiency)

Specific information on production and use of recycled and secondary aggregates, practical, regulatory and business related issues associated with their use. Focused at small and medium sized businesses.

WRAP AggRegain

<http://aggregain.wrap.org.uk>

Case studies, technical guidance, tools, direct links to the Highways Agency Specifications for Highway Works, European Standards and quality protocols.

Mineral Products Association

www.mineralproducts.org (select products/recycled aggregates)

Resources on sustainable use of aggregates.

The Concrete Centre

www.sustainableconcrete.org.uk

Provides information relating to carbon impacts and sustainable concrete construction.

TRL

www.trl.co.uk

Publishes a range of reports relating to aggregates applications, mainly in relation to highways applications.

BRE

www.brebookshop.com

IHS BRE Press publishes Digests, Information Papers and reports relating to ground engineering and sustainable materials including aggregates, cements, concrete for application in the built environment.

Appendix B

Selection of aggregates containing recycled or secondary material

B1 Selection of appropriate material for hardcore (adapted from BRE Digest DG 522^[30])

Recycled concrete aggregate is perhaps the most commonly used hardcore material. Box B1 summarises some of the main considerations in its appropriate selection and use.

Hardcore is a commonly used construction term that describes the compacted material used for supporting ground-bearing floor slabs. It is not unusual to find companies that offer to sell hardcore with little or no idea what will be provided and its quality. Such material may not have been produced to the relevant BS EN aggregates standard (BS EN 13242^[32]) and may be considered to be waste within the meaning of the EU Waste Framework Directive.

In practice, a range of source materials (alone or in combination) may be suitable for use as hardcore. Such source materials may include natural materials, crushed concrete and crushed masonry from demolition of buildings and structures. In each case, the material must be capable of being well compacted and be 'clean', (ie the quantities of any 'contaminants' are insignificant). This means that the material should be free of any organic material such as timber, should not contain deleterious amounts of sulfates (such as might be found in some types of brick and adhering gypsum plaster).

By far the most common materials currently used for hardcore are Type 1 and Type 2 unbound mixtures, as specified respectively by Clauses 803 and 804 of *Specification for Highway Works Series 0800*^[18] which are widely available throughout the UK. Very similar material has been in use for highway construction for several decades, so the behaviour of the material is generally well understood by practitioners. Older names 'MOT Type 1' and 'MOT Type 2', are still commonly used for these materials by some suppliers and specifiers.

When free of potentially reactive substances and when appropriately placed and compacted, both materials perform well as hardcore (see Table A2). Type 1 and Type 2 unbound mixtures may both contain crushed rock, crushed slag, crushed concrete, crushed masonry, well-burnt non-plastic shale, gravel and sand. However, as explained later, not all the above listed constituents are necessarily welcome in material to be used as hardcore owing to some of them possibly containing potentially chemically reactive substances. It will therefore be important to ask the supplier to declare the types and amounts (if any) of recycled and secondary materials that are included in any aggregates mixture to be used as hardcore. If these include steel slag, blastfurnace slag, IBAA or burnt colliery spoil, expert advice should be sought on material suitability for use. The following can give rise to problems of volume expansion in service:

- Recycled and secondary material containing sulfate and pyrite (such as crushed masonry with a high content of gypsum [calcium sulfate] plaster, bricks with a high sulfate content, sulfates in burnt colliery spoil).
- Steel slag (may have a residual tendency to hydrate and expand to an extent unacceptable in hardcore beneath buildings).
- Blastfurnace slag from old slag banks.
- Incinerator bottom ash aggregate when this has a substantial sulfate content.

- There are a number of specific restrictions in relation to blastfurnace slag and steel slag (BRE IP on ferrous slag IP 18/01^[54]).

BRE Digest 427 (Part 3)^[55] gives practical recommendations for the selection and quality control of materials for engineered fill for the foundations of low rise buildings. Such materials are selected, placed and compacted to an appropriate specification. Trenter and Charles^[56] provide a model specification for such engineered fills. BR 424^[28] is a much more comprehensive document which provides a detailed account of BRE research findings and their significance for appropriate and successful building developments on fill, including engineered fill and non-engineered fills (which are often by-products from human activity, eg old waste tips or opencast mining infill). Most problems that do occur are associated with developments on non-engineered fills.

Box B1 Crushed concrete as hardcore

Recycled concrete aggregate (RCA) is perhaps the recycled material most widely used form of unbound material to support ground floor slabs. Provided that it is clean and well graded, it is ideal for use in most situations. An exception is any site where there is a substantial amount of sulfate in soil or groundwater.

BRE Special Digest 1 (SD 1)^[57] gives guidance on assessing such aggressive conditions. RCA should not be used where it is subject to conditions equivalent to aggressive ground category ACEC Class 2 or above. For neutral pH conditions (ie no acidity) this equates to not using RCA when sulfate levels are Class 2 or above. The lower limit of this Class 2 is 400 mg/l SO₄ for sulfate in groundwater, and 500 mg/l SO₄ for sulfate in a 2:1 water:soil extract test.

There is not a specific set of performance parameters covering materials for use as hardcore. However, when free of potentially reactive substances and when appropriately placed and compacted, materials classified as Type 1 or Type 2 unbound mixtures perform well as hardcore.

B2 Selection of aggregates for vibro stone columns

B2.1 General

The two critical issues that apply to any aggregates used to form vibro stone columns are its grading and stability. Several types of recycled or secondary aggregate can be suitable. The material should be fit for the purpose. The phrase 'stone which is clean, hard and inert' conveys the spirit of the requirements for vibro stone column material, but does not define acceptable criteria for material type, grading, hardness or chemical stability. These factors will largely determine the ability of the columns to fulfil the design requirements and it is important to clarify minimum acceptable standards for the materials used to form vibro stone columns. The material used should be chemically inert and remain stable in the particular soil and groundwater conditions (current or anticipated) at the site. Any risk of contamination to groundwater, surface water, soils and to human health also needs to be considered.

The requirements for unbound aggregates are given in BS EN 13242^[32]. The material selected to form the vibro stone columns should be able to withstand the impact forces of the vibrating poker and retain long-term integrity under the applied foundation loads. It should not excessively crush or break down during compaction or under long-term static loads applied in service. The hardness can be defined by the Los Angeles Coefficient^[58] but under older standards, was expressed in terms of aggregate crushing value (ACV) or aggregate impact value (AIV). Recycled aggregate supplied from most of the larger suppliers will be certificated under UKAS accreditation for Los Angeles Coefficient and possibly one or more of these other parameters.

The ACV and 10% fines value (TFV) have been replaced by the Los Angeles abrasion (LAA) value. Historically (and according to industry sources), a maximum ACV of 30 or minimum TFV of between 50 and 100 kN (saturated), (with 120 kN applicable to some of the more powerful bottom-feed units), has been required for vibro stone

column aggregate. While no recognised correlation exists between ACV, TFV and LAA, an LAA value of between 30 and 40 is recognised within the industry as being acceptable for vibro stone columns, dependent upon specific application. Material with an ACV or AIV greater than 30% may not be suitable for stone column construction. Some colliery spoils, eg shaley siltstones and mudstones, will readily crush and are unlikely to be suitable for stone columns. The shape of the aggregate particles is important as this can reduce the resistance to impact and crushing. The effect of possible increases in the moisture content or full saturation of stone column material should be considered; aggregate likely to degrade or significantly weaken when saturated in-situ is not suitable for column construction.

The grading of material used to form vibro stone columns should be appropriate for compaction to form a dense column fully interlocked with the surrounding ground. The grading will also depend on the method and plant used to form the columns. Nominal single-sized materials with a maximum fines content (material of silt and clay sized particles) of 5% are generally appropriate. The maximum and minimal particle size to be specified depends on the method used to install the column (top or bottom feed; wet or dry). BR 391 *Specifying Vibro Stone Columns*^[25] refers to standards that have now been superseded but provides a useful source of practical guidance.

B2.2 Suitable recycled and secondary aggregates for vibro stone columns

Industry sources (unpublished) indicate that approximately 30% of the materials used in vibro stone columns comes from recycled and secondary sources and this is principally derived from crushed concrete and spent rail ballast sources. Regarding spent rail ballast, there seems to be a common misconception that it is always contaminated. Most ballast tends to come from open running track, so there is less risk of significant contamination. Where there are any contamination issues/concerns, the ballast can be washed prior to delivery to site. Further information is given in papers by Serridge^[59] and others^[60].

The material for vibro stone columns may be specified to comply with the *Specification for Highway Works* (Series 0600^[27] and 0800^[18]) for properties such as grading and maximum particle size and be appropriate for the method of construction. Further guidance is available in BRE Report 391 *Specifying Vibro Stone Columns*^[25]. Steel slag should not currently be used in the UK in vibro stone columns because of the potential issues with expansion.

B3 Sub-base for domestic drives

Domestic driveways have to be built to the same standards as lightly trafficked roads since they need to carry wheeled traffic.

The safest option if wanting to crush and use site-discarded masonry for sub-base is to:

- Process masonry as a recycled aggregate as necessary to comply with the quality requirements of the Aggregates Quality Protocol.
- Crush the recycled aggregate and incorporate it into *Specification for Highway Works* specification Type 1 or Type 2 unbound mixtures.
- Follow *Specification for Highway Works* Clause 802 in respect of laying and compaction.

At first sight, the specification for pathways (adjacent to houses) might be considered to be not so demanding. However, it should be remembered that in practice, there is often a backfilled service trench beneath these, so the specifications for trench backfilling should be part of any consideration of the specification for the sub-base to pathways.

Appendix C

Avoiding damage to buildings

- Lessons learnt

Table C1 Some recycled and secondary aggregate materials used as hardcore that have resulted in damage to buildings in the UK (adapted from BRE Digest DG 522 Part 2)^[31].

Material	Where used in the UK	Problems arising from use	Refs.
Unburnt colliery spoil Waste material from the deep mining of coal, derived mainly from the rocks that lie adjacent to the coal seams	In and around former coalfield areas in England, Wales and Scotland	The chemical reactions of pyrite (iron sulphide) may lead to bulk expansion of hardcore and the potential to cause floor uplift. Unburnt colliery spoil may also contain significant amounts of clay. This can result in swelling of the hardcore if it is compacted in a dry condition then subsequently becomes wet. Cases of expansion due to unburnt colliery spoil are relatively uncommon	[61]
Burnt colliery spoil (red shale) This material resulted from the combustion of the residual coal and carbonaceous matter in old, poorly consolidated tips	In and around former coalfield areas in England, Wales and Scotland	Sulfate attack to concrete floor slabs and oversite concrete when used as hardcore material in moist conditions (eg groundwater or leaking services). The result is expansion of the concrete, typically producing doming and cracking of floors and displacement of adjacent walls	[57]
Furnace bottom ash (black ash)	In and around former heavy industrial areas in England, Wales and Scotland	Ash and cinders from coal-burning boilers and furnaces typically contain water-soluble sulfates. When used as hardcore material, problems have arisen similar to those associated with use of burnt colliery spoil	[57]
Incinerator bottom ash aggregate	In any area of the UK	Incinerator bottom ash aggregate results from the combustion of domestic refuse. It may contain a significant concentration of sulfates, though no related cases of damage to buildings from sulfate attack are known to BRE. Two cases are known of uplift of a floor slab which have resulted from expansion of one source of IBAA used as hardcore	
Oil shale residue	In the Lothians area of Scotland. An oil extraction industry was based here through to 1963 that left a legacy of some 200 million tons of spent shale in waste tips	Some problems of sulfate attack to concrete floor slabs have reputedly arisen from the use of 'spent' oil shale (blaes) taken from the waste tips (bings)	[61]
Blastfurnace slag	In areas of England, Scotland and Wales where iron and steel was produced. Often these coincided with coalfield areas	Some blastfurnace slags from old slag banks have undergone expansive reactions when used as fill and hardcore. Modern air-cooled blastfurnace slags are not susceptible to attack from sulfates by this mechanism	[61]

Material	Where used in the UK	Problems arising from use	Refs.
Steel slag from old slag heaps	In areas of England, Scotland and Wales where iron and steel was produced. Often these coincided with coalfield areas	<p>Steel slag from old slag heaps (also known as old bank slags), can contain free lime and magnesia. The reaction in the presence of moisture produces a volume expansion that may continue for many years.</p> <p>A substantial number of houses in the Midlands and North of England have suffered floor uplift and outward displacement of walls below damp proof course owing to long-term expansion of hardcore material made up of unstable steel slag.</p> <p>It should be noted that steel slag aggregates from modern steel production are quality assured materials and are suitable for a range of uses other than as hardcore, eg trench reinstatement, hydraulically bound mixtures.</p>	[61] [62]
Demolition rubble containing gypsum plaster or bricks with a high soluble sulfate content	In all areas of the UK, but particularly in cities such as Bristol and Hull where rubble from bombed buildings was used after World War 2	<p>Rubble from building demolition may contain gypsum plaster or bricks with a high soluble sulfate content, which, when conditions are moist, can cause sulfate attack to oversite concrete or floor slabs.</p> <p>In a 1970s bungalow in the West Midlands, such sulfate attack caused some 50 mm domed uplift and cracking of oversite concrete, which in turn damaged overlying sleeper walls and suspended wooden floors.</p>	[61] [57] [62]
Crushed concrete placed in a sulfate environment	In areas of the UK where sulfate is found in geological strata (see Figure C2 of BRE Special Digest 1 ^[57])	<p>Crushed concrete may expand due to sulfate attack if placed in a location where there is sulfate in soil or groundwater.</p> <p>In one case, recycled concrete used below floor slabs in a coalfield area reacted with sulfates in groundwater resulting in expansion.</p>	[57] [61] [62]

Appendix D

Applications of recycled and secondary aggregates

Table D1 Recycled and secondary aggregates in residential construction – opportunities (based on information published by WRAP on the AggRegain website)^[17]

Application	Product	Examples	Types of recycled or secondary aggregates in products	Recycled or secondary materials allowed in the coarse aggregate (or whole material where stated)	Other recycled or secondary materials allowed	Relevant standards
Residential buildings						
Garage floor (reinforced)	Reinforced concrete	Designated concrete RC30/35	China clay sand and stent and RCA (see note 3)	20% standard practice	ggbs and pfa (see note 3)	BS 8500-2 ^[1] PD 6682-1 ^[37] BS EN 12620 ^[6]
Garage floor (unreinforced)	Unreinforced concrete	Designated concrete GEN3 Standardised prescribed concrete ST4	China clay sand and stent, and RCA	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] PD 6682-1 ^[37] BS EN 12620 ^[6]
Internal (ground) floors	Concrete floor, housing	Designated concrete GEN2, standardised prescribed concrete ST3	China clay sand and stent, RCA, RA may also be used where specification allows	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] PD 6682-1 ^[37] BS EN 12620 ^[6]
Trenches for services						
Concrete bedding	–	Type A (ST4 concrete)	Blastfurnace and zinc slag, china clay sand and stent, foundry sand, IBAA (see note 3), pfa and RCA and slate aggregate	Up to 100% where specification allows	–	PD 6682-1 ^[37] BS EN 12620 ^[6]
Concrete surround	Unreinforced concrete	Type S, Type T, Type Z (ST2 concrete)	China clay sand and stent, RCA, recycled glass and slate aggregate	Up to 100% where specification allows	–	<i>Specification for Highway Works</i> Series 0500, PD 6682-1 ^[37] BS 8500-2 ^[1]

Application	Product	Examples	Types of recycled or secondary aggregates in products	Recycled or secondary materials allowed in the coarse aggregate (or whole material where stated)	Other recycled or secondary materials allowed	Relevant standards
Trenches for services						
Lower trench fill	Unbound material	<i>Specification for Highway Works Class 8 lower trench fill (Class 1, 2 and 3 fill)</i>	China clay sand and stent, RA, RCA and recycled glass	Up to 100% where specification allows	–	<i>Specification for Highway Works Series 0500 and 0600, PD 6682-6^[33], BS EN 13242^[32]</i>
Granular or sandy bedding	Unbound material	<i>Specification for Highway Works Type B, F, N, S, and T</i>	RCA, RA and recycled asphalt (the latter can form up to 50% of the material)	Up to 100% where specification allows	–	BS EN 13285 ^[45] , PD 6682-6 ^[33] , BS EN 13242 ^[32] , <i>Civil Engineering Specification for the Water Industry (CESWI)^[63]</i>
Granular or sandy surround	Unbound material	<i>Specification for Highway Works Type S and T</i>	RCA, RA and recycled asphalt (the latter can form up to 50% of the material)	Up to 100% where specification allows	–	BS EN 13285 ^[45] , PD 6682-6 ^[33] , BS EN 13242 ^[32] , <i>Civil Engineering Specification for the Water Industry (CESWI)^[63]</i>
Foam concrete	Foamed concrete	–	Recycled and secondary materials can form parts of the fine aggregate and cementitious components of the concrete providing they comply with the <i>Specification for Highway Works</i>	Up to 100% where specification allows	–	<i>Specification for Highway Works Series 1000^[39] and HAUC Specification for the Reinstatement of Openings in Highways (SROH)^[64]</i>
Sub-structures						
Selected granular fill	Unbound material	<i>Specification for Highway Works Type 6N and 6P granular materials</i>	RCA, RA, recycled glass, recycled asphalt	Up to 100% where specification allows	–	<i>Specification for Highway Works Series 0600^[27]</i>
Mass concrete fill	Unreinforced fill	Designated concrete GEN1 S3, standardised prescribed concrete ST2 S3, designed or proprietary Concrete	RCA, RA	Up to 100% where specification allows	–	BS 8500-2 ^[1] , PD 6681-1 ^[37] , BS EN 12620 ^[6]
Basement level structural concrete	Fully buried reinforced concrete	Designated concrete RC25/30 to RC40/50	RCA	Up to 100% where specification allows	–	BS 8500-2 ^[1] , PD 6681-1 ^[37] , BS EN 12620 ^[6]

Application	Product	Examples	Types of recycled or secondary aggregates in products	Recycled or secondary materials allowed in the coarse aggregate (or whole material where stated)	Other recycled or secondary materials allowed	Relevant standards
Shallow foundations						
Raft foundation (reinforced)	Reinforced concrete buried foundation	Designated concrete RC25/30 to RC40/50	RCA	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] , PD 6681-1 ^[37] BS EN 12620 ^[6]
Blinding concrete	Unreinforced concrete	Designated concrete GEN1 S3, standardised prescribed concrete ST2 S3	RCA, RA	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] , PD 6681-1 ^[37] BS EN 12620 ^[6]
Strip footing (unreinforced)	Unreinforced concrete	Designated concrete GEN1 S3, standardised prescribed concrete ST2 S3	RCA, RA	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] , PD 6681-1 ^[37] BS EN 12620 ^[6]
Trench footing	Trench fill (unreinforced concrete)	Designated concrete GEN1 S4, standardised prescribed concrete ST2 S4	RCA, RA	20% standard practice. Can be up to 100% where specification allows	ggbs and pfa (see note 3)	BS 8500-2 ^[1] , PD 6681-1 ^[37] BS EN 12620 ^[6]
<p>Note 1: Table D1 excludes factory-made, pre-cast products (concrete blocks, tiles, reconstituted stone, pre-cast structural beams or columns etc) which may also contain recycled or secondary aggregates</p> <p>Note 2: The content of Table D1 is based on the construction applications part of the opportunities section of the AggRegain website http://aggregain.wrap.org.uk/opportunities and the AggRegain specifier tool http://aggregain.wrap.org.uk/specifier/index.html</p> <p>Note 3: RCA (recycled concrete aggregate), ggbs (ground granulated blastfurnace slag), pfa (pulverised fuel ash), IBAA (incinerator bottom ash aggregate), RA (recycled aggregate).</p>						

Appendix E

Aggregates codes and standards

E1 CEN and BS aggregates standards

Materials suitable for use as recycled or secondary aggregates fall into two broad groups:

- Demolition, reclaimed and other construction materials – approximately 60% are already used as aggregates and fill.
- Industrial by-products such as:
 - colliery spoil: widely used for bulk fill
 - china clay waste: used in some areas as mortar and concreting sands
 - power station ash: used as a cement substitute within ready-mixed concrete and for block making
 - blastfurnace slag from the iron and steel industries: used as aggregates and when ground to form ground granulated blastfurnace slag (ggbs) as cementitious materials
 - slate waste.

Box E1 lists the relevant national guidance according to the PD 6682 Series (Parts 1 to 6).

Box E1 National guidance according to the PD 6682 Series (Parts 1 to 6)

PD 6682 Series. Grading and properties categories applicable to aggregate used in the UK

Part 1: *Aggregates for Concrete – Guidance on the Use of BS EN 12620*^[37]

Part 2: *Aggregates for Bituminous Mixtures and Surface Treatments for Roads, Airfields and Other Trafficked Areas – Guidance on the Use of BS EN 13043*^[65]

Part 3: *Aggregates for Mortar – Guidance on the Use of BS EN 13139*^[66]

Part 4: *Lightweight Aggregates for Concrete, Mortar and Grout – Guidance on the Use of BS EN 13055-1*^[38]

Part 5: *Lightweight Aggregates for Bituminous Mixtures and surface Treatments and for Unbound and Bound Applications Excluding Concrete, Mortar and Grout – Guidance on the Use of BS EN 13055-2*^[67]

Part 6: *Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction – Guidance on the Use of BS EN 13242*^[68]

Unlike the (now withdrawn) British Standard for aggregates (BS 882:1992 *Specification for Aggregates from Natural Sources*) for concrete, the European Standards make no distinction between primary (natural) and recycled and secondary aggregates. The national guidance documents and European Standards (current from January 2004) are listed in Table E1.

Table E1 European Standards for aggregates (from 1 January 2004)

BS EN 12620+A1	<i>Aggregates for Concrete</i>
BS EN 13043	<i>Aggregates for Bituminous Mixtures and Surface Treatments for Roads, Airfields and Other Trafficked Areas*</i>
BS EN 13055-1	<i>Lightweight Aggregate for Concrete</i>
BS EN 13055-2	<i>Lightweight Aggregate for Bound and Unbound Materials</i>
BS EN 13139	<i>Aggregates for Mortar</i>
BS EN 13242+A1	<i>Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction</i>
BS EN 13285	<i>Unbound Mixes – Specification</i>
BS EN 13383	<i>Armourstone</i>
BS EN 13450	<i>Aggregates for Railway Ballast</i>
BS EN 450-1	<i>Fly Ash for Concrete</i>
BS EN 14227-3	<i>Fly Ash for Bound Materials</i>
BS EN 14227-4	<i>Fly Ash for Hydraulically Bound Mixtures</i>
BS EN 13108-1	<i>Bituminous Mixtures. Material Specifications. Asphalt Concrete</i>
BS EN 13108-2	<i>Bituminous Mixtures. Material Specifications. Asphalt Concrete for Very Thin Layers</i>
BS EN 13108-3	<i>Bituminous Mixtures. Material Specifications. Soft Asphalt</i>
BS EN 13108-4	<i>Bituminous Mixtures. Material Specifications. Hot Rolled Asphalt</i>
BS EN 13108-5	<i>Bituminous Mixtures. Material Specifications. Stone Mastic Asphalt</i>
BS EN 13108-6	<i>Bituminous Mixtures. Material Specifications. Mastic Asphalt</i>
BS EN 13108-7	<i>Bituminous Mixtures. Material Specifications. Porous Asphalt</i>
BS EN 13108-8	<i>Bituminous Mixtures. Material Specifications. Reclaimed Asphalt</i>
*Additional requirements for constituents of bituminous mixtures are included within national guidance provided by PD 6691 ^[69] and the BS EN 13108 Bituminous mixtures Series (Parts 1 to 8) ^[70] .	
PD 6691 must be the principle reference document for mixtures covered by BS EN 13108 Parts 1, 4 and 5. A specifier is not able to select appropriate mixtures from EN 13108 Series without national guidance from PD 6691.	

Further information and factsheets on standards and national guidance documents can be downloaded from the Mineral Products Association website (www.mineralproducts.org).

E2 Highways Agency MCDHW, Volume 1: Specification for Highway Works

Table E2 lists the document number and name of the Series documents in Volume 1 of the Highways Agency: *Specification for Highway Works*^[18]. Note that guidance on the use of these specifications is given in *Manual of Contract Documents for Highway Works, Volume 2: Notes for Guidance on the Specification for Highway Works*^[71]. These have a similar Series order but are designated as, for example, Series NG800^[72].

Table E2 Series listing in Highways Agency, Manual of Contract Documents for Highway Works, Volume 1, *Specification for Highway Works*

Document number	Document name
Series 0000	Introduction
Series 0100	Preliminaries
Series 0200	Site Clearance
Series 0300	Fencing
Series 0400	Road Restraint System (Vehicle and Pedestrian)
Series 0500	Drainage and Service Ducts
Series 0600	Earthworks
Series 0700	Road Pavements General
Series 0800	Road Pavements – Unbound, Cement and Other Hydraulically Bound Mixtures
Series 0900	Road Pavements – Bituminous Bound Materials
Series 1000	Road Pavements – Concrete Materials
Series 1100	Kerbs, Footways and Paved Areas
Series 1200	Traffic Signs
Series 1300	Road Lighting Columns and Brackets, CCTV Masts and Cantilever Masts
Series 1400	Electrical Work for Road Lighting and Traffic Signs
Series 1500	Motorway Communications
Series 1600	Piling and Embedded Retaining Walls
Series 1700	Structural Concrete
Series 1800	Structural Steelwork
Series 1900	Protection of Steelwork Against Corrosion
Series 2000	Waterproofing for Concrete Structures
Series 2100	Bridge Bearings
Series 2200	Not Used
Series 2300	Bridge Expansion Joints and Sealing of Gaps
Series 2400	Brickwork, Blockwork and Stonework
Series 2500	Special Structures
Series 2600	Miscellaneous
Series 3000	Landscape and Ecology
Series 5000	Maintenance Painting of Steelwork
Appendix A	Quality Management Systems
Appendix B	Product Certification Systems
Appendix C	Certification for Proprietary Products
Appendix D	Statutory Type Approval
Appendix E	Type Approval/Registration
Appendix F	Publications Referred to in the Specification
Appendix G	Petrographical Examination of Aggregates for Alkali-Silica Reaction
Appendix H	Quality Records
Note: Guidance on the use of these specifications is given in <i>Manual of Contract Documents for Highway Works, Volume 2</i> ⁷¹ .	

E3 Volume 7 of the Highways Agency – *Design Manual for Roads and Bridges*

Volume 7 of the Highways Agency – *Design Manual for Roads and Bridges*, which is entitled *Pavement Design and Maintenance, HD35/04 (Conservation and the Use of Secondary and Recycled Materials^[23])* is a very useful summary document which describes provisions for the use of different types of secondary and recycled materials in applications such as pipe bedding, fill, sub-base and concrete, listing the permitted aggregate materials in these applications against the relevant Series of the *Specification for Highway Works*.

See www.concrete.net.au/publications/pdf/RecycledAggregates.pdf.

Appendix F

Aggregates for use in concrete

F1 Introduction

Recycled and secondary aggregates can be used very successfully as a proportion of the coarse aggregate fraction in concrete. The current British and European Standards (BS EN 12620^[6] and BS EN 13055-1^[36] and accompanying national guidance documents PD 6682-1^[37] and PD 6682-4^[38]), that apply to aggregates for concrete *do not discriminate against non-primary aggregates*. Together, these two aggregates standards and national guidance documents cover the use of natural, manufactured and recycled and secondary aggregates for concrete. BS 8500-2 (the British Standard for concrete)^[1], imposes additional requirements and limits on recycled and secondary aggregates for use in concrete. Note that these Standards do not actually use the term 'secondary' aggregates, but such aggregates are also covered by the Standards, albeit under a different name. Secondary aggregates derived from the extraction of china clay, slate and other construction materials have been used successfully in concrete production. The MPA website^[73] gives a useful overview of the European Standards for concrete.

The most frequent application of recycled aggregates in concrete involves the use of specific types; coarse RA or RCA which are closely defined in BS 8500 (see section F2). The use of fine recycled aggregates in conventional concrete is uncommon and often undesirable, for reasons explained below.

The introduction of the European Standard for concrete, BS EN 206-1^[50] and complementary British Standard BS 8500-2^[1], means that some types of recycled aggregates can be used in certain types of concrete. Selection of appropriate recycled aggregates for use in concrete needs to be carefully quality controlled, since for use elsewhere recycled aggregates may be sourced from a variety of materials (some unsuitable for concrete) arising from construction and demolition (eg, concrete, bricks, tiles), highway maintenance (asphalt plantings), excavation and utility operations. The quality of the recycled aggregate is entirely dependent on the quality of the materials processed, the selection and separation processing used, and the degree of final processing.

Annex A to the European Standard for aggregates for concrete (EN 12620)^[6] lists and groups the source materials that were considered in the development of this Standard, and their status (including their history of use and whether any special requirements apply to their use).

The use of some types of recycled aggregates (eg RCA) in concrete may require higher cement content, leading to an increase in the CO₂ emissions associated with the concrete. However, the use of cement replacement materials (such as pfa and ggbs) to partially replace Portland cement provides a powerful means for reducing the embodied CO₂ associated with the concrete mix.

Typical applications for ready-mixed concretes made with recycled aggregates include foundations, ground floor slabs and concrete driveways. Recycled aggregates can also be used in pumpable flowing concrete mixes suitable for concrete wall construction using the approach known as insulated concrete formwork (ICF) construction.

F2 Use of coarse recycled aggregate and recycled concrete aggregate in concrete

The following recommendations are extracted from BS 8500-2^[1]. They are not intended as a comprehensive guide and the reader should refer to the standard for a full description of the requirements and limitations of these aggregates in concrete.

For the purposes of this guide, coarse aggregate is defined as having a particle size exceeding 4 mm.

In the context of concrete, BS 8500 specifically defines two main types of recycled coarse aggregate:

- RCA (recycled concrete aggregate), which is mainly crushed concrete.
- RA (recycled aggregate), which is mainly crushed masonry.

Coarse RCA and coarse RA for use in concrete need to conform with the requirements for coarse RCA or RA (in terms of percentage content of masonry, fines, sulfates, lightweight impurities etc) as specified in Table 2 of BS 8500-2^[1]. Mixtures of coarse RCA or coarse RA and natural aggregates need to conform to the general and other appropriate requirements for aggregate specified in BS EN 12620^[6] and to the general requirements for normal weight aggregates in BS 8500.

F3 General limitations on use of coarse RA or RCA

There are currently some further general limitations to the use of RA and RCA in concrete including:

- Aggregates must be used in accordance with the requirement set out in the British Standard for Concrete, BS 8500.
- Recycled concrete aggregate may not be suitable for aggressive ground or severe freeze-thaw conditions (see BS 8500).
- Recycled aggregates (excluding recycled concrete aggregate) require the specifier to include source specific requirements with respect to alkali silica reaction and sulfate limits (see BS 8500).

F4 Designated concretes – limitations on use of recycled aggregates or recycled concrete aggregates

Where coarse RA or RCA is to be used in designated concretes (as described in BS 8500-2 section 6.2.2):

- It needs to conform with certain composition, chemical and general requirements.
- In designated concretes RC20/25 to RC40/50, its proportion shall not be more than a mass fraction of 20% of coarse aggregate except where the specification permits a higher proportions to be used.
- Where RA is used, the issues of physical and chemical requirements need to be addressed, documented and approved by the certification body.
- Unless otherwise specified, the maximum aggregate size (of the RA or RCA) shall be 20 mm.

Coarse RA or RCA can comprise any mass fraction of the coarse aggregate in designated concretes GEN0 to GEN3. Neither RA nor RCA are permitted in designated concrete intended to resist the most severe conditions for freeze–thaw attack.

F5 Prescribed concretes – limitations on use of recycled aggregates or recycled concrete aggregates

Coarse RA and RCA may be used in prescribed concretes provided they comply with the requirement of Section 4.3 of BS 8500-2.

Coarse RCA may be used in standardised prescribed concretes provided they comply with the requirement of Section 4.3 of BS 8500-2.

F6 Use of fine recycled aggregates and recycled concrete aggregates in concrete

Provisions for the use of fine RCA and fine RA are not given in BS 8500 (note 6 of Part 2) but this does not completely preclude their use in certain concretes. However, great care needs to be exercised that sufficient is known of the source material, that significant quantities of deleterious materials are not present, in particular the risk of contamination of crushed masonry by gypsum plaster, which can lead to durability and expansion problems in concrete. RA aggregate is not permitted in ST mixes.

A type of lightweight, low strength flowable concrete (known as foamed concrete) made using a range of fine materials (such as washing plant fines, foundry sand, crushed glass) is available^[74]. Foamed concrete has applications as base and sub-base for trench reinstatement or lower trench fill but mixes suitable for use in foundations are also likely to become available.

F7 General and practical advice to the specifier on the use of recycled and secondary aggregates in concrete

- Engage with ready-mixed concrete companies to ensure the availability, best and most effective use of RAs prior to specification. The area/regional, or in some cases the national technical manager should be contacted for advice.
- For most practical applications, RAs should only be introduced as a replacement for the coarse aggregate element of fresh concrete and at a percentage that does not adversely affect the concrete's fresh or hardened properties. The latest editions of BS EN 12620 *Aggregates for Concrete*^[6] and PD 6682-2^[65] which are anticipated to be published during 2013 are likely to provide additional advice in this area.
- Consideration should be given as to whether or not the introduction of secondary and/or RA into the concrete will provide a more sustainable and environmentally sound project, as their introduction into other forms of construction material and applications may provide more viable options in both economic and environmental terms.

Most of the major ready-mixed concrete companies will have the technical expertise to produce and supply concrete containing a range of RAs, and at a range of percentage replacement levels (ie replacing primary aggregate).

Consideration should also be given to:

- Availability and subsequent transportation distance (of the aggregate and concrete).
- Need to increase the cement/combination content of concrete when RA is introduced due to any variation in material quality.

- Production, processing, screening, washing and grading of recycled materials to improve their consistency and quality to a level that may be considered suitable for introduction into concrete. (Note: Alternative uses to concrete [such as some unbound materials], may require significantly less processing than is required for use in concrete.)

A guidance document, published by the Concrete Centre, gives practical guidance on the issues to consider when seeking to specify sustainable concrete^[75].

Appendix G

An introduction to cement materials and low carbon cements

G1 Cement replacement materials

The primary construction cement used worldwide is Portland cement, a material which was first developed in the 1800s.

The manufacturing process for Portland cement, however, has a major global CO₂ impact and reducing this impact has become a significant focus of the construction industry. The main reason for this major impact is that one of the principal materials used in its manufacture is calcium carbonate (limestone), which evolves CO₂ when heated to high temperatures in order to produce cement 'clinker'. Further CO₂ is also emitted from the burning of fuels (such as coal) in the cement kiln and grinding of the cement clinker. It is estimated that, worldwide, approx 7.5% of man-made CO₂ emissions are due to Portland cement manufacture^[76] with a current annual tonnage of around 2 billion tonnes of CO₂.

The cement producers and ready-mixed concrete industries use secondary materials to reduce the impact of cement and concrete on CO₂ emissions in three different ways:

- Through so called concrete mixer blends which can be made by the concrete producer based on the application (this is the most common form of cement replacement).
- Combinations (or composite cements), which are factory-made cements made by the cement producer (this form of cement replacement has a much smaller market).
- Through the use of carbon neutral fuels in the cement kiln.

The finely ground secondary materials used in blended cements or combinations act as reactive partial replacements to Portland cement and/or as fillers. As these secondary materials bring a lower CO₂ burden than Portland cement, they can be used to reduce the CO₂ impact of the finished concrete. The main materials widely used for this purpose in the UK include ground granulated blastfurnace slag (ggbs) and pulverised fuel ash (pfa). Ground limestone is sometimes used as filler although other materials can also be used. Pfa and ggbs have a long track record of many decades of successful use in concrete and, when used appropriately, bring additional benefits such as reduced temperature rise in the setting concrete and improved long term durability^[12].

Table G1 CEM II and CEM III composite cements (conforming to BS EN 197-1^[77]) that are generally available in the UK

Designation of cement combination	Description
Portland-fly ash cement (CEM II/A-V)	CEM I cement with 6% to 20% mass fraction of pfa
Portland-fly ash cement (CEM II B-V)	CEM I cement with 21% to 35% mass fraction of pfa
Portland-limestone cement (CEM II/A-L and CEM II/A-LL)	CEM I cement with 6% to 20% mass fraction of limestone
Blastfurnace cement (CEM III/A)	CEM I cement with 36% to 65% mass fraction of ground granulated blastfurnace slag
Blastfurnace cement (CEM III/B)	CEM I cement with 66% to 80% mass fraction of ground granulated blastfurnace slag
Portland slag cement (CEM II/B-S)	CEM I cement with 21% to 35% mass fraction of ground granulated blastfurnace slag

In practical terms, specifiers and contractors can seek to minimise the carbon footprint of concrete through:

- Avoiding over-prescriptive specifications which exclude use of these low carbon materials/cements in ready-mixed concrete and by specifically requesting a low carbon concrete from their readymix supplier.
- Requesting/purchasing a CEM II cement (which are widely available in bagged form) that meet the requirements of EN 197-1^[77], in preference to traditional plain Portland cement (CEM I). Table F1 summarises the main types of EN 197-1 compliant cements that are available in the UK. CEM III cements are not currently available in bagged form in the UK. A detailed consideration of modern factory-made composite cements and their equivalent combinations is outside the scope of this guide.

CEM II cements are increasingly becoming the default option as bagged cements for general use (rather than CEM I, Portland cement). The major ready-mix suppliers are also increasingly offering purchasers the option of a specific 'sustainable-badged' brand of concrete within their range of mixes. The major ready mix suppliers are all familiar with the use of ggbs and/or pfa in their concrete mixes and either or both of these materials are widely available throughout the UK.

G2 Low carbon cements

Several types of low carbon cements (which do not contain any Portland cement) are under development. These materials have a much lower carbon footprint than conventional cements but are not yet commercially available in Europe. There is a good deal of activity worldwide both to commercialise these cements and to generate comprehensive evidence of their performance and durability and develop practical guidance. Examples include the geopolymers (or alkali activated binders), belite/sulfoaluminate cements, and magnesia-based cements^[78] (see Box G1).

Box G1 Low carbon alternative cements

Alternative cements: While not currently available as commercial products, concern about CO₂ emissions associated with cement manufacture has led to the development of a number of alternatives to Portland cement. While the time for these to reach the market may be significant, these cements have the potential to be used in the future to substantially reduce the embodied CO₂ of concrete. More information is available from BRE Information Paper IP 7/08 *Cements with Lower Environmental Impact*^[78].

References

- 1 BSI. Concrete – Complementary British Standard to BS EN 206-1 – Specification for constituent materials and concrete. BS 8500-2. London, BSI, 2006.
- 2 BSI. Quality management systems. Requirements. BS EN ISO 9001. London, BSI, 2008.
- 3 BSI. Concrete – Complementary British Standard to BS EN 206-1 – Method of specifying and guidance for the specifier. BS 8500-1. London, BSI, 2006.
- 4 Business Link. Recovering and using recycled aggregates. www.businesslink.gov.uk/bdotg/action/layer?topicId=1086445254.
- 5 WRAP. Opportunities to use recycled materials in house building. Reference guide. Banbury, WRAP, September 2004. http://aggregain.wrap.org.uk/procurement/quick_wins/opportunities_to.html.
- 6 BSI. Aggregates for concrete. BS EN 12620:2002 + A1:2008. London, BSI, 2008.
- 7 WRAP. WRAP quality protocol for aggregates from inert wastes. http://aggregain.wrap.org.uk/quality/quality_protocols.
- 8 Environment Agency. State of progress for each material. www.environment-agency.gov.uk/business/topics/waste/114460.aspx.
- 9 Planning Portal. Code for Sustainable Homes: A step-change in sustainable home building practice. December, 2006. www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf.
- 10 WRAP. Benefits and drivers. <http://aggregain.wrap.org.uk/procurement/benefits>.
- 11 Sustainable Concrete. Sheet C1 – Embodied CO₂ of concrete and reinforced concrete. www.sustainableconcrete.org.uk/PDF/C1%20CISCF%20WG2%20Embodied%20CO2%20of%20UK%20Concrete%2027%20Nov%2008.pdf.
- 12 The Concrete Society. Cementitious materials, Technical Report 74. Camberley, the Concrete Society, 2011.
- 13 http://aggregain.wrap.org.uk/sustainability/try_a_sustainability_tool/co2_emissions.html.
- 14 MPA Aggregates carbon reduction portal (online). www.aggregatescarbonreduction.com/index.html.
- 15 BRE. Green Guide to Specification. www.bre.co.uk/greenguide/podpage.jsp?id=2126.
- 16 WRAP. www.wrap.org.uk.
- 17 AggRegain. <http://aggregain.wrap.org.uk>.
- 18 Highways Agency. Manual of Contract Documents for Highway Works (Volume 1, Highways Agency – Specification for Highway Works). Series 0800, Road pavements – Unbound, cement and other hydraulically bound mixtures. London, Highways Agency, 2009.
- 19 WRAP. Performance related approach to use of recycled aggregates. Project code: AGG0074. WRAP, February 2007. http://aggregain.wrap.org.uk/news/performance_related.html.
- 20 British Geological Survey. Construction aggregates, mineral planning factsheet. February 2007. www.bgs.ac.uk/downloads/start.cfm?id=1355.
- 21 The Definition of Waste: Development Industry Code of Practice Version 2 March 2011. ISBN 978-1-90504-6. CL:AIRE (contaminated land in real environments). www.claire.co.uk.
- 22 Butcher AP, Powell JJM and Skinner HD (eds). Reuse of foundations for urban sites: a best practice handbook. EP75. Bracknell, IHS BRE Press, 2006.
- 23 Highways Agency. Welsh Assembly, Scottish Executive and the Department of the Environment for Northern Ireland. Design Manual for Roads and Bridges: Volume 7, Section 1, Part 2, HD 35/04. Conservation and use of secondary and recycled materials. The Stationery Office, London, 2004.
- 24 The Environment Agency. The use of air-cooled blastfurnace slag as an unbound aggregate in the construction industry. QPA/Environment Agency Joint Guidelines. London, The Environment Agency, 2007.
- 25 Watts K. Specifying vibro stone columns. BRE Report 391. Bracknell, IHS BRE Press, 2000.

- 26 Patel JP. Broader use of steel slag aggregates in concrete, MSc thesis. Cleveland, Cleveland State University, December 2008.
- 27 Highways Agency. Manual of Contract Documents for Highway Works, (Volume 1, Highways Agency. Specification for highway works) Series 0600, Earthworks. London, Highways Agency, 2009.
- 28 Charles JA and Watts KS. Building on fill: geotechnical aspects. BRE Report BR 424 (2nd edition). Bracknell, IHS BRE Press, 2001.
- 29 Charles JA. Geotechnics for building professionals. BRE Report BR 473. Bracknell, IHS BRE Press, 2005.
- 30 Longworth I. Hardcore for supporting ground floors of buildings. BRE Digest DG 522, Part 1. Bracknell, IHS BRE Press, 2011.
- 31 Longworth, I. BRE Digest DG 522. Part 2. Placing hardcore and the legacy of problem materials. Bracknell, IHS BRE Press, 2011.
- 32 BSI. Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction. BS EN 13242:2002 + A1:2007. London, BSI, 2007.
- 33 BSI. National annex PD 6682-6. Aggregates – Aggregates for unbound and hydraulically bound materials for use in civil engineering works and road construction. Guidance on the use of BS EN 13242. PD 6682-6. London, BSI, 2009.
- 34 Highways Agency. Manual of Contract Documents for Highway Works, (Volume 1, Highways Agency. Specification for Highway Works). Series 0500, Drainage and service ducts. London, Highways Agency, 2009.
- 35 NHBC Foundation. A simple guide to sustainable drainage systems for housing. Milton Keynes, NHBC Foundation, 2010. www.nhbcfoundation.org/Portals/0/NF22_Sustainable_Drainage_Systems.pdf.
- 36 BSI. Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout. BS EN 13055-1. London, BSI, 2002.
- 37 BSI. National annex PD 6682-1. Aggregates. Aggregates for concrete. Guidance on the use of BS EN 12620. BSI, London, 2009.
- 38 BSI. National annex, PD 6682-4. Aggregates. Lightweight aggregates for concrete, mortar and grout. Guidance on the use of BS EN 13055-1. BSI, London, 2003.
- 39 Highways Agency. Manual of Contract Documents for Highway Works, (Volume 1, Highways Agency. Specification for Highway Works). Series 1000, Road pavement – concrete materials. London, Highways Agency, 2009.
- 40 Price WF. Mix design specification for low strength concretes containing recycled and secondary aggregates. 2002. www.wrap.org.uk/downloads/MixDesignSpecificationorLowStrengthConcretesContainingRecycledAndSecondaryAggregates.ab8cfe76.344.pdf.
- 41 Mineral Products Association. Construction and surfacing of parking areas including private drives. Asphalt applications 1, 2009. www.mineralproducts.org/documents/AA1_Final.pdf.
- 42 National Green Specification. www.greenspec.co.uk.
- 43 CIRIA. Source control using constructed pervious surfaces. Hydraulic, structural and water quality performance issues. Report C582. London, CIRIA, 2002.
- 44 WRAP. Promoting the use of applications incorporating recycled and secondary aggregates in HBM. Research report (in 7 parts). Banbury, WRAP, 2005. http://aggregain.wrap.org.uk/opportunities/materials/hydraulically_bound/index.html.
- 45 BSI. Unbound mixtures. Specifications. BS EN 13285. BSI, London, 2010.
- 46 NHBC. NHBC standards 2011. Part 2 – Materials. NHBC, Milton Keynes, 2011.
- 47 NHBC. NHBC standards 2011. Part 4 – Foundations. NHBC, Milton Keynes, 2011.
- 48 NHBC. NHBC standards 2011. Part 5 – Substructure and ground floors. NHBC, Milton Keynes, 2011.
- 49 NHBC. NHBC Standards 2011. Part 9 – External works. NHBC, Milton Keynes, 2011.
- 50 BSI. Concrete. Specification, performance, production and conformity. BS EN 206-1. BSI, London, 2000.
- 51 BSI. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements. BS 7533-3. BSI, London 2005.
- 52 Dunster AM, Longworth TI, Nixon PJ, Lane SJ and Collins RJ. Development of sites containing expansive ferrous slags. BRE IP 8/05. Bracknell, IHS BRE Press, 2005.
- 53 Coton C. The use of recycled aggregates in concrete. 24-25 CONCRETE. Crowthorne, Concrete Society, 2011.
- 54 Dunster A. Blastfurnace slag and steel slag: their use as aggregates. BRE IP 18/01. Bracknell, IHS BRE Press, 2001.
- 55 Low-rise buildings on fill: Engineered fill. BRE DG 427-3. Bracknell, IHS BRE Press, 1998.

- 56 Trenter NA and Charles JA. A model specification for engineered fills for building purposes. *Proceedings of the Institution of Civil Engineers, Geotechnical Engineering* 119: 219–30, 1996.
- 57 Concrete in aggressive ground. BRE SD 1 (3rd edition). Bracknell, IHS BRE Press, 2005.
- 58 BSI. Methods for the determination of resistance to fragmentation. BS EN 1097-2. BSI, London, 2010.
- 59 Serridge CJ. Achieving sustainability in vibro stone column techniques. *Proceedings of the Institution of Civil Engineers, Engineering Sustainability*, 158: December 2005, Issue ES4, 211–222.
- 60 Jefferson I, Gaterell M, Thomas AM and Serridge CJ. Emissions assessment related to vibro stone columns. *Proceedings of the Institution of Civil Engineers Ground Improvement*, 2010, 163.
- 61 Hardcore. BRE Digest 276. Watford, BRE. Bracknell, IHS BRE Press, 1992.
- 62 Pye PW and Harrison HW. BRE building elements: Floors and flooring – performance, diagnosis, maintenance, repair and the avoidance of defects. BR 460. Bracknell, IHS BRE Press, 2003.
- 63 Civil Engineering Specification for the Water Industry (CESWI), 7th Edition. Swindon, WRc, March 2011.
- 64 Code of Practice. Highway Authorities and Utilities Committee (HAUC), Specification for the Reinstatement of Openings in Highways (SROH) (3rd ed), 2010.
- 65 BSI. Aggregates. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas. Guidance on the use of BS EN 13043. PD 6682-2. BSI, London, 2009.
- 66 BSI. PD 6682-3: Aggregates for mortar – Guidance on the use of BS EN 13139. London, BSI, 2003.
- 67 BSI. PD 6682-5: Lightweight aggregates for bituminous mixtures and surface treatments and for unbound and bound applications excluding concrete, mortar and grout – Guidance on the use of BS EN 13055-2. London, BSI, 2005.
- 68 BSI. PD 6682-6: Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction – Guidance on the use of BS EN 13242. London, BSI, 2009.
- 69 BSI. National annex. Guidance on the use of BS EN 13108 Bituminous mixtures. Material specifications. PD 6691. London, BSI, 2010.
- 70 BSI. Bituminous mixtures series (Parts 1 to 8). BS EN 13108. London, BSI, 2006.
- 71 Highways Agency. Manual of Contract Documents for Highway Works, (Volume 2 Notes for Guidance on the Specification for Highway Works). London, Highways Agency, 2009.
- 72 Highways Agency. Manual of Contract Documents for Highway Works, (Volume 2 Notes for Guidance on the Specification for Highway Works) Series NG 800, Road pavements - unbound, cement and other hydraulically bound mixtures. London, Highways Agency, 2009.
- 73 Mineral Products Association (MPA). European standards for concrete. www.concretecentre.com/codes_standards.aspx.
- 74 Jones MR, McCarthy A and Dhir RK. Recycled and secondary aggregates in foamed concrete. STBF 13/13C, 2005. <http://aggregain.wrap.org.uk/opportunities/materials/concrete/rsa.html>.
- 75 The Concrete Centre. Specifying sustainable concrete. Camberley, The Concrete Centre, 2011. www.concretecentre.com/online_services/publication_library/publication_details.aspx?PublicationId=758.
- 76 World Business Council for Sustainable Development. Batelle Institute/ World business council for sustainable development – toward a sustainable cement industry, 2002. www.wbscd.org/sectoral/cement.
- 77 BSI. Cement. Composition, specifications and conformity criteria for common cements. EN 197-1:2011. London, BSI, 2011.
- 78 Quillin K. Cements with lower environmental impact. BRE IP 7/08. Bracknell, IHS BRE Press, 2008.

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NHBC Foundation recent publications

Understanding overheating – where to start: An introduction for house builders and designers

This guide is a useful introduction to the topic of overheating and covers the principles of overheating as well as factors that increase or reduce the risk. Seven case studies are provided to demonstrate a number of reasons for overheating, including location of the site, errors in design or the way in which the home is being used by its occupants. **NF 44** July 2012

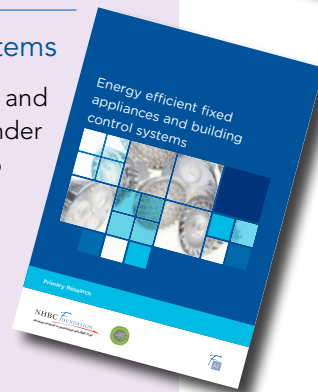


Energy efficient fixed appliances and building control systems

This report examines the range of energy efficient fixed appliances and building control systems that are either currently available or are under development, and considers how these might be incorporated into new low or zero carbon homes.

As we head towards the zero carbon future for new homes, and begin to address the huge challenge of reducing energy consumption, it is clear that the correct choice of energy-efficient technologies is likely to make a valuable contribution.

NF 43 July 2012



A survey of low and zero carbon technologies in new housing

This work has been conducted in partnership between the NHBC Foundation and the University of Reading. It examines which low and zero carbon technologies are being used by the house-building sector in response to the challenge of producing low carbon homes.

Further it presents some finding on how occupants are using, adapting and benefiting, or not, from their low and zero carbon technologies. **NF 42** May 2012



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NHBC Foundation publications in preparation

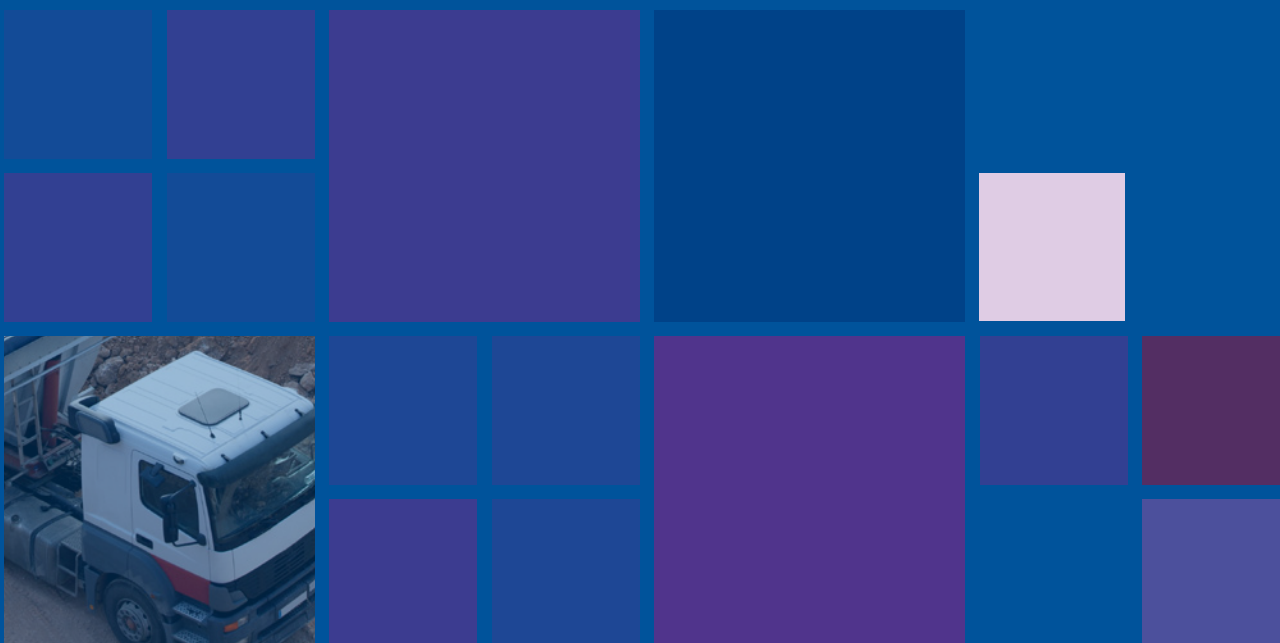
- Building sustainable homes at speed: Risks and rewards
- Lessons from the German Passivhaus experience
- Overheating in highly insulated homes

The use of recycled and secondary materials in residential construction

The use of recycled and secondary materials as aggregates in construction for applications such as pipe bedding and concreting aggregate (as well as in the more 'traditional' uses as 'hardcore', fill and road materials) is increasing.

The sustainability benefits of correctly using recycled and secondary construction materials supports the Government's sustainability agenda and gives developers credits for use of recycled content in construction projects. Conversely their incorrect use can lead to unsatisfactory performance and the need for costly remedial works.

This clear, detailed and practical guide describes how to source, correctly specify and use secondary and recycled materials in residential construction (illustrated by case studies and examples). It also provides key information on how to avoid incorrect use (and consequent unsatisfactory performance) of recycled and secondary materials.



The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the UK's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.