Creating markets for recycled resources

Promoting the use of applications incorporating recycled and secondary aggregates in hydraulically bound materials: Study report

R&D Report: Aggregates

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Executive Summary

Increased use of recycled and secondary aggregates (RSA) could be promoted by the wider use of hydraulically bound material (HBM) which have the potential to be made with 100% RSA. HBM has been widely used in continental Europe, but is less prevalent in the UK, except, perhaps, for the use of cement bound material (CBM) in highways applications such as road base and sub-base.

The first of a series of New European Standards for HBM has now been published and the Highways Agency is in the process of including these within the UK Specification for Highway Works. This will be followed by inclusion within the Design Manual for Road and Bridge Works. These developments will go some way towards increasing the use of HBM, however potential users need to be made aware of the potential for RSA in HBM and to promote the use of HBM across a range of sectors covering both buildings and infrastructure. There are also real benefits to be gained from the use of RSA in HBM.

The current project is intended to promote the use of applications incorporating RSA in HBM. The objective of the research is to produce guidance on the costs, technical benefits, cases studies of successful use, durability etc. The guidance is across a range of sectors covering both buildings and infrastructure.

The research has provided:

- Technical guidance documents regarding the use of applications incorporating RSA in HBM
- Six case studies, illustrating the use of RSA in HBM in a range of applications.

Our overall objectives of this work have been to produce guidance on the costs, technical benefits, durability as well as cases studies of successful use of HBM containing RSA.

The objective has been met through the following work programme:

1. Prepare technical guidance documents (Task 1)
2. Prepare a study report collating the findings of the research, likely future developments, research needs and durability (Task 2)
3. Preparation of case studies (Task 3)
4. Dissemination (Task 4)

This study report is the output of Task 2. It draws together the outcomes of Tasks 1 to 3.

There is a need for pre-normative research to develop improved durability performance tests and provide service life information. There is also a need for improved publicly available design guidance for the use of HBM and in particular of HBM using RSA in some applications (eg working platforms).

This report was prepared for the DTI. The views expressed are those of the authors and not necessarily those of DTI.

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1 Introduction

Increased use of recycled and secondary aggregates (RSA) could be promoted by the wider use of hydraulically bound material (HBM) which have the potential to be made with 100% RSA. HBM has been widely used in continental Europe, but is less prevalent in the UK, except, perhaps, for the use of cement bound material (CBM) in highways applications such as road base and sub-base.

The first of a series of New European Standards for HBM has now been published and the Highways Agency is in the process of including these within the UK Specification for Highway Works. This will be followed by inclusion within the Design Manual for Road and Bridge Works. These developments will go some way towards increasing the use of HBM, however potential users need to be made aware of the potential for RSA in HBM and to promote this across a range of sectors covering both buildings and infrastructure. There are also real benefits to be gained from their use (see below).

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The research has provided:

- Technical guidance documents regarding the use of applications incorporating RSA in HBM
- Six case studies, illustrating the use of RSA in HBM in a range of applications.

These cover the following technical areas/applications:

Guidance documents:

- Major roads
- Minor roads and paved areas
- Heavy duty paving
- Erosion protection
- Liners

Case studies:

- Stabilisation of canal dredgings for erosion protection
- Stabilised pfa to provide erosion protection for the core of a flood protection dam
- HBM road base containing stabilised soil for a major road
- Heavy duty paving for a marine port facility
- Lime modified and cement stabilised alluvial deposits for piling platform
- Use of steel slag for the creation of a wheelchair access

Guidance on durability issues associated with HBM has also been provided in Appendix C.

The technical guidance and case studies are targeted primarily at structural/civil engineering practices and main contractors to enable them to offer alternative solutions incorporating high quantities of RSA within the specifications of major clients.

The guidance was prepared under contract to DTI and WRAP (contract reference STBF/013/00010c).

The work has highlighted the opportunities for the increased use of RSA in HBM, not just for roads but also for other construction uses such as water engineering and sea defences. This report is intended to collate the findings of the research, indicate what future developments are likely to be and any research necessary to support future aims. The report also includes details of durability of HBM and problems that could be caused by sulphate attack (including thaumasite formation) and tests necessary to preclude this.

This report was prepared for DTI. The views expressed are those of the authors and not necessarily those of DTI.

1.1 Introduction to hydraulically bound mixtures (HBM)

HBM are mixtures that set and harden by hydraulic reaction. They include CBM (i.e. 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.

This project includes within its scope, the stabilisation of soil with hydraulic binders. This offers the advantage of using indigenous materials instead of importing aggregates to the site.

HBM has potential to be use in a range of paving and non-paving applications. Use of RSA in the HBM offers some additional benefits. Use of HBM offers the following general advantages:

- HBM construction is well known and versatile in terms of availability of plant and materials.
- HBM can be produced by "mix-in-plant" or "mix-in-place" equipment by in-situ stabilising existing material.
- Plant for laying and compaction of HBM is similar to that required for laying and compacting other paving materials such as unbound layers or bituminous bound products.
- Some HBM mixtures allow the re-use of materials available on site (eg soil, demolition wastes) with savings on imported primary material (avoiding the Aggregates Levy) and disposal costs (avoiding sending materials to landfill).
- HBM has proven energy saving benefits. ETSU General Information Report 49. illustrates the energy benefits of using HBM. These include the significant energy savings associated with the use of a cold mix technology and utilisation of by products such as pfa and slag.
- HBM assists in winning work by meeting or exceeding client requirements for "green" procurement.

Since the aggregate for HBM is locked into the hardened mixture, the potential for leaching is minimised, opening up opportunities for the use of a wide range of RSA. However, the possibility of leaching may need to be considered for some materials. Table 1 lists the range of RSA that can be used in HBM.

Table 1: RSA suitable for use in HBM (adapted from Sherwood, 1994)

Potential	RSA
High	China clay sand, recycled concrete aggregates, air-cooled blastfurnace slag, GBS*, burnt colliery spoil, PFA*, spent oil shale, recycled asphalt, other road arisings, slate aggregate, incinerator bottom ash aggregates (IBAA).
Medium**	Unburnt colliery spoil, general demolition debris
Low**	basic oxygen (BOS) slag, electric arc furnace (EAF) slag

*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.

1.1.1. Opportunities for HBM in paving applications

This is discussed in relation to:

- Major roads
- Minor roads and paving
- Heavy duty paving.

Major roads

HBM bases and subbases using cement (CBM) are increasingly being used more widely. The advent of the 'design & build' contract and the use of analytical pavement design techniques are the main reasons for this; there is no reason to suspect that this trend should not continue. With the recent introduction of European standards and the incorporation of these standards in the Specification for Highway Works, the use in bases and subbases of the 'new' HBMs based on binders made from granulated slag and fly ash should establish a greater foothold than to date, relieving even more the draw on primary materials.

With regard to the stabilization of on-site material for capping and subbases, this market will continue to grow, especially as many jobs today have a significant surplus and thus a disposal requirement.

Minor roads and paving

HBM in minor roads has had limited use in new build in recent years. However, there has been significant application of HBM in maintenance of minor roads particularly for structural recycling employing cement. For paving of car-parks and hard-standing, the opportunities for HBM are significant. The desire to make the optimum use of site arisings will continue to drive these opportunities.

Heavy duty paving

Traditionally, heavy duty paving has provided a healthy market place for HBM, particularly CBM. Good and continuing performance means that this trend is likely to continue. The use of fly ash particularly has also established a healthy position in heavy duty paving applications.

1.1.2. Opportunities for HBM in non-paving applications

Non-paving applications are, without a doubt, exciting areas for HBM with limitless opportunities. At the present time, market penetration is small but could become significant. This is discussed in relation to:

- Erosion protection
- Liners
- Piling platforms.

Erosion protection

Although there is no knowledge or record of the use of HBM for erosion protection in the UK, HBM is widely used for this application in the United States and elsewhere. With an increasing tendency for flooding and the inadequacy of existing defences, there will be a need for more investment in erosion protection. The right publicity for the advantages of HBM for this application should open up the market and opportunities.

Low permeability liners

As with erosion protection, there is no record of industrial use of HBM for liners. However, there is interest within the waste industry which sees the combination of cementitious binders and their own particular waste as the logical way to contain and neutralize their waste either on mass or as liners. Publicity is again the key here for future market penetration.

Piling platforms

Hydraulic stabilization of the existing ground has been used in lieu of imported granular material. Current data suggests that this has been limited to one or two piling companies but the benefits are so significant that the market will undoubtedly grow with little outside pressure. The use of slag and fly ash should reduce the reliance on the primary, cements and lime.

2 Description of the project

Our overall objectives in this work have been to produce guidance on the costs, technical benefits, durability as well as cases studies of successful use of HBM containing RSA.

In the past year, BRE has prepared for DTI and WRAP in excess of 40 case studies on the use of RSA. Our approach to addressing these objectives has been to develop new guidance documents based on the those in BRE report 215-993 together with reports and information of case studies already produced by BRE for DTI or WRAP and material sourced from project partners John Kennedy and David York. For the case studies, BRE developed and build upon existing case studies. We have also identified new case studies through contacts with industry and used the information gained to develop the technical guidance. The guidance covers a range of sectors including both buildings and infrastructure.

The objective has been met through the following work programme:

- Prepare technical guidance documents (Task 1)
- Prepare a study report collating the findings of the research, likely future developments, research needs and durability (Task 2)
- Preparation of case studies (Task 3)
- Dissemination (Task 4)

This study report is the output of Task 2. It draws together the outcomes of Tasks 1 to 3.

3 Technical guidance

The technical guidance documents are included in Appendix A. Key features are set out below.

3.1 Paving applications

3.1.1. Major roads

This guidance document covers the use of HBM for major roads including motorways, bypasses, and significant town or city roads including their structural maintenance. It covers the opportunities, benefits, and procedures for the use of HBM in such applications and highlights case studies and other key documents for further reference. The guidance will be of particular value and interest to consultants, local authorities, developers and contractors. The application of HBM incorporating RSA for minor roads and paved areas, including residential/commercial roads, car parks and lorry parks, and for heavy duty paving such as airfields and ports, is covered in Technical Guidance document 3. These applications are covered by Technical guidance documents 2 and 3 respectively in this series.

3.1.2. Minor roads and paved areas

Unlike major roads for which there are well known and documented procedures for the application of HBM, the situation for minor roads and paving is less clear and obvious. The information is available but is scattered across a number of not so obviously applicable documents. The guidance document on minor roads and paved areas is an attempt to bring all the relevant references together.

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 retail and leisure developments and hardstandings for commercial vehicles. The guidance, which has a particular focus on design, will be of interest to developers, contractors, and civil engineering consultancy practices.

It should be noted that this document covers the use of HBM in applications designed to carry traffic up to and including the normal legal road axle of 10 tonnes or wheel loads of 5 tonnes. The application of HBM for heavy duty paving for ports and airfields, where wheel loads of 10 tonnes and more are commonplace, is covered within a separate guidance document.

3.1.3. Heavy duty paving

This guidance document is intended to cover the use of HBM for loading in excess of those on public roads. Such loadings are typically experienced in ports and airfields, where wheel loads of 10 tonnes and more are commonplace.

The document particularly highlights the advantages of using recycled and secondary aggregates (RSA) in HBM. It also covers the opportunities, benefits, and procedures for the use of HBM in heavy duty paving and highlights case studies and other key documents for further reference.

Since the advice given is based on port and airfield documentation, it is acknowledged that many port and airfield operators will be aware of what is contained in this guidance document. However, there are other situations, such as container transfer, storage and handling facilities, where heavy duty paving will be required and the advice should therefore be of value to developers, consultants and contractors likely to be involved with such projects.

3.2. Non-paving applications

3.2.1. Erosion protection

For over 50 years in the United States and other parts of the world, HBM have been widely and extensively used in marine and fluvial projects to provide slope protection for channels, spillways, coastal shorelines and inland reservoirs. In the UK, the application of HBM in marine and fluvial projects has been more limited although there are excellent examples. These examples particularly illustrate the wide contribution that can be made by recycled and secondary aggregates (RSA) and indigenous materials to reduce the use of primary aggregates.

The purpose of this guidance document is to draw together the relevant information on the use of HBM for erosion control and protection and give guidance on its use as a viable technical and economic alternative to the more conventional techniques employing concrete or rip-rap which require the extensive utilisation of primary aggregates. The document covers:

- the benefits of using HBM and RSA for erosion protection
- general concepts
- specific details or issues
- references referring to constituents, mixture design, construction and field requirements, control and testing of construction.

3.2.2. Low permeability Liners

HBM have been extensively used and have a long track record overseas in projects including low permeability liners for water-storage reservoirs, waste-water treatment lagoons, sludge-drying beds, ash-settling ponds and solid-waste landfills including certain hazardous wastes.

The purpose of this guidance document is to draw together the relevant information and give guidance on the use of HBM liners as a viable technical and economic alternative to clay or clay/HPDE membrane/packed aggregate liners. The document covers:

- the benefits of using HBM and RSA for liners
- general concepts
- specific details
- references or issues on constituents, mixture design, construction and field requirements, control and testing of construction.

3.2.3. Working platforms

There are opportunities for use of HBM in the construction of working platforms. The term “working platforms” is restricted to ground-supported working platforms for tracked plant, constructed of granular material. The working platform includes associated ramps and accesses as well as the platform itself.

HBM and cement stabilisation can potentially be used in the construction of working platforms in two different ways:

- To produce a hardened mixture for the construction of the platform itself
- Hydraulic binders can also be used to improve the material properties of the sub-grade

The authors are aware of the use of stabilised materials for platforms by several UK companies. *It has not been possible to source details or to provide a design guidance document at present.* However, there is a case study (see Appendix B).

4 Case studies

The six case study documents are included in Appendix A. A brief summary of each is given below (Table 2):

Table 2: Case studies

Case study title	Location	Application	Advantage of using HBM
Forth & Clyde Canal – Refurbishment of Locks 4 to 5	Central belt, Scotland	Water resources – Canal refurbishment	Hydraulically treat contaminated silt dredgings to solidify and stabilise as an engineering fill. Avoided expensive disposal costs. No imported aggregate required. Reduced lorry movements. Contaminants 'locked up' chemically. Engineering fill easily handled, placed and compacted using traditional methods.
New Mill Dam Construction	Truro, Cornwall (South West region, England)	Water resources - Flood control dam	Ease and speed of construction. Workability (over a long period of time), consistency and 'pastiness' of mix. PFA contributed to performance of HBM Cost savings of 10-60% compared to earth fill or concrete alternatives.
The A27 Polegate Bypass	Polegate, East Sussex (South East region, England).	Road sub-base construction	Used existing material on site. No imported aggregate required. Transport pollution associated with disposing/importing materials on site reduced. Significantly stronger sub-base, as strength increases over time, reducing thickness required.
Rainbow Terminal, Immingham Docks	Immingham, Lincolnshire (Yorkshire and Humberside region, England)	Port Paving – heavy duty pavement for storage of structural steel	A CBM base which was a more cost effective alternative than traditional CBM3 base. Cheapest solution whilst still providing performance criteria, as specified. Higher strength and lower density than conventional CBM3 mix.
Genome Campus Extension, Hinxton, Cambridge	Hinxton, Cambridgeshire (East of England region)	Piling Platform Construction	Used existing highly variable alluvial deposits on site. Reduced transport of waste off site and aggregates onto site. Strong, stiff and durable working platform. After use became permanent formwork for all reinforced concrete piling caps as well as main sub-base layer for building ground floor slabs.
Anne Hathaway's Cottage Wheelchair Access Path	Stratford-Upon-Avon, Warwickshire (West Midlands region, England)	Wheelchair access path	Kept with the general aesthetics of the property. 99% recycled content. Use almost immediately. Far greater strength than conventional gravel dressings. Flexible, easily workable and can be laid in virtually all weathers

The six case studies have illustrated the real cost and technical benefits associated with the use of HBM containing RSA. Particular examples from the above include:

- Cost savings on import costs (for primary aggregates) and disposal costs where indigenous materials have been used (in road construction and erosion protection)
- Cost savings (associated with speed of construction, less use of material) in dam construction compared with earth dam alternative designs

Case studies are given in full in Appendix B.

5 Durability of HBM and test methods

HBM have a long track record of good durability performance in the UK and overseas. Appendix C of the report discusses the issue of durability of HBM including:

- resistance to weather (principally frost) and particularly with respect to the use of HBM in roads
- volume or dimensional stability including resistance to sulphate attack.

Relevant guidance and test methods are given in the European standards that relate to aggregates for unbound and hydraulically bound mixtures and those covering the hydraulically bound mixtures themselves. Guidance is also given in this report on specification for weather (frost) resistance, volume stability and avoidance of sulfate reactions (including thaumasite sulfate attack).

A more detailed discussion of the issues surrounding the durability of HBM and relevant test methods is given in Appendix C of this report.

6 Research needs

The project has highlighted the need for the following fundamental and pre-normative research to underpin the utilisation of HBM:

- Development of durability tests for HBM mixtures (specifically for weather and dimensional stability) to support European standardisation

- Development of a site performance test for slow setting and hardening HBM

- Development of comprehensive design guidance for working platforms (thicknesses, binders, mixtures etc)

- Research on other applications for stabilised materials (such as lime piles or columns) and development of guidance on design parameters

- Information on service life and long term chemical stability of particular materials

7 Conclusions and recommendations

7.1. Conclusions

Hydraulically bound mixtures (HBM) offer a range of real cost saving and technical benefits to the stakeholders in construction projects. These include versatility, savings in energy and resources.

HBM mixtures allow the appropriate use of indigenous materials (saving on the import of primary aggregates) and RSA alternatives to primary aggregates.

There are a range of applications of HBM in paving and non-paving uses. The “non-road” applications such as piling platforms, liners and erosion protection, and heavy duty paving have a large potential which is under-exploited in the UK.

HBM have a good track record of durability. Nevertheless, there is a need for pre-normative research to develop improved durability performance tests and provide service life information.

7.2. Recommendations

In the light of these conclusions we make the following recommendations:

- It appears and is expected that HBM have a good record of durability. However, improved long term performance tests would increase user confidence and not exclude aggregate materials unnecessarily. The possibility of leaching may need to be considered with some materials. Action: WRAP to consider funding work in this area.
- There is a need for design guidance on use of HBM in working platforms. Action: WRAP to consider funding work in this area.

8 References

ETSU (1997) general information report 49. Energy Minimisation in road construction and maintenance. ETSU, Harwell, Didcot, Oxon.

Sherwood, P.T. (1994), A review of the use of waste materials and by-products in road construction. Contractor report 358, Transport Research Laboratory, Crowthorne.