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Recycled aggregates

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Recycled aggregates (crushed concrete and brick masonry) have long been used in the UK and overseas construction industries. However, due to a lack of suitable specifications, there has been little basis for applying quality control. Because these materials are often thought to be inferior to natural aggregates, they are mainly used in lower grade applications. Undoubtedly, though, suitable-quality recycled aggregates may be used successfully in higher grade applications such as structural concrete. Recent international advances in the drafting of specifications now enables greatly improved guidance to be given in the UK.

This Digest covers the use of crushed concrete and masonry, but not the recycling of bituminous-bound aggregates used in road construction. It will be of interest to architects, structural engineers, specifiers, and professionals in the aggregates and recycling industries.

Introduction

Recycled aggregates are normally defined as aggregates resulting from the reprocessing of mineral construction materials (ie composed predominantly of crushed concrete and brick masonry). Construction waste (ie new materials wasted on construction sites through over-ordering, breakage etc), as well as demolition waste, may provide source material. Recycled aggregates can contain, in some circumstances, significant quantities of natural aggregates; but excessive quantities of other materials such as wood, metal and plastic need to be removed before the aggregate is fit for use. Specifications are required to limit potentially deleterious quantities of impurity, and also to cover the use of recycled aggregate as an 'artificial aggregate' excluded by specifications for natural aggregate (see the panel on page 2).

Aggregates reclaimed from unwanted fresh concrete by washing away the unset cement are sometimes referred to as recycled aggregates. These aggregates are generally indistinguishable from the aggregates used to make the concrete in the first place, and should be subject to the same specifications as those used originally.

Figure 1 This 500 m^3 concrete strong floor at BRE's Cardington laboratory used 100 tonnes of Class RCA(III) coarse aggregate

General description

A fundamental requirement in any specification for a material is to give a general description of its composition. For recycled aggregate (RCA), the relative proportions of concrete to brick masonry is the most critical issue. Three classes may be used for definition (see Table 1).

Class RCA(I) defines the lowest quality material. It could have relatively low strength and a relatively high level of impurity. It might contain up to 100% brick or block masonry but could possibly be composed mainly of concrete but with a level of impurity higher than allowed in Class RCA(II). The strength (as measured by the 10% fines value test for aggregate in BS 812-111) for brick masonry is usually in the region of 70 kN.

Class RCA(II) defines a relatively high quality of material with a relatively low content of impurity. It will normally be composed almost entirely of crushed concrete but in some circumstances may contain an appreciable amount of natural aggregate. The strength (as measured by the above 10% fines value test) for crushed concrete is usually in excess of 100 kN.

Class RCA(III) defines a mixed material with a similar impurity level to Class RCA(I) but with a slightly wider potential usage; for example 80/20 blends of natural aggregate/Class RCA(III) may be accepted as coarse aggregate in all grades of concrete.

Table 1 Classes of recycled aggregate (RCA)

Class	Origin (normal circumstances)	Brick content by weight
RCA(I)	Brickwork	0–100%
RCA(II)	Concrete	0–10%
RCA(III)	Concrete and brick	0–50%

Blends with natural aggregate

When recycled aggregates are blended with natural aggregates, the blending proportions should be stated. Some recycled materials may already contain significant quantities of natural aggregate in addition to the natural aggregates released from concrete by the crushing process. Where this is appreciable (above 20%), the material should be treated as a blend and the approximate proportions should also be stated. Natural aggregates of good quality normally enhance the properties of recycled aggregates; however the following points should be noted.

- If an RCA blend contains more than 20% uncrushed gravel, it may not be suitable for use as Highways Specification Type 1 sub-base (see Table 2).
- The sulfate limits for crushed concrete and brickwork (see Table 2) may not be appropriate to all types of natural aggregate.

Blends: general principles

Crushed concrete and brickwork may be blended with other types of material provided that the quality of the blended material complies with a specification appropriate to the proposed end use (see panel below). The approximate proportions of any blend should be stated – see notes under *Test methods, Composition* on page 5.

Component materials not meeting a specification suitable to the end use should be considered to be impurities.

Impurities

Recommended limits on potentially deleterious components are given in Table 2.

Specifications for aggregate in the UK – situation in 1998

Aggregates for concrete are normally specified by BS 882, *Specification for aggregates from natural sources for concrete*, with BS 1047 for air-cooled blastfurnace slag or BS 3797 for lightweight aggregates sometimes being given as alternatives. Although good general guidance on recycled aggregates is given in BS 6543, this standard is rarely quoted in contract documents. *Specification for highway works*[1], however, will permit the use of crushed concrete for pavement construction if it complies with the 'quality and grading requirements of BS 882'. Unbound applications for recycled aggregates are covered in *Specification for highway works* and Digest 276.

Following the publication in Denmark, The Netherlands and Japan of specifications for the use of recycled aggregates in concrete, an international document was prepared by RILEM in 1994. This has formed the basis of specification clauses for recycled aggregate being prepared for inclusion in European Standard specifications for aggregate (CEN Technical Committee TC154 'Aggregates'). Some years will elapse before this integrated approach can become operational. In the meantime, explicit guidance on the specification of recycled aggregates is required in the UK. It is the aim of this Digest to bridge the gap between current UK practice and the introduction of standards for aggregate which give full coverage to the use of recycled materials.

Other specification requirements

Use as fill or hardcore (building construction)

The grading of the aggregate should be suitable to permit full compaction.

Further guidance is given in Digest 276.

Use as granular material for drainage or civil engineering fills

Details for various uses (including agriculture and the water industry) have been collated in Volume 2 of the BRE Report *Efficient use of aggregates and bulk construction materials.* Environmental requirements in addition to the limits in Table 2 may be needed for drainage.

Use in road construction

The *Specification for highway works*[1] gives details for the use of crushed concrete, ie Class RCA(II), in granular sub-base material Type 1 or 2. Aggregates for use in pavement concrete or cement bound material (CBM) categories 3, 4 and 5 may be crushed concrete 'complying with the quality and grading requirements of BS 882.' (See below for further guidance on uses in concrete). Details are also given for 6F1 and 6F2 capping layers which may contain aggregates of Classes RCA(I),(II)or(III). Similarly CBM categories 1 and 2 may contain Classes RCA(I),(II)or(III).

Mixed concrete/brick materials of Class RCA(III) have been used as sub-base materials in The Netherlands, and there may be opportunities for their use in the UK, subject to the approval of the Resident Engineer for each individual contract.

Guidance on the recycling of bituminous aggregates (eg road planings) is given in the *Specification for highway works* and in The Highways Agency Technical Memorandum HD35/95[2]. Mixtures of concrete and bituminous materials are not specifically covered in UK guidance although there should be compliance with the requirements of 6F1, 6F2, CBM1 and CBM2. Concrete/bituminous mixtures are used as sub-base materials in some countries (eg Canada and Denmark) and thus there may be opportunities for use in the UK contracts with the approval of the Resident Engineer. Similarly there has been overseas experience in the use of bituminous materials and mixed concrete/bitumen in CBMs which has potential application in the UK.

Use in concrete

Recycled aggregates of Classes RCA(I), (II) or (III) complying with the quality and grading requirements of BS 882 may be used in concrete to BS 5328 (see IP 5/94 and IP 3/97). Aggregates not complying with the grading requirements in BS 882 may still be used in compliance with BS 5328 if trial mixes indicate that concrete of suitable quality can be produced.

Table 2 Maximum recommended levels of impurity (by weight)

	Use in concrete as coarse aggregate	Use in road construction – unbound/cement bound material Sub-base Type 1 or 2, or CBM 3,4 or 5: **RCA(II) only.** Capping layer 6F1 or 6F2, or CBM 1 or 2: **normally RCA(I), (III)**	Hardcore, fill or granular (drainage) material
Asphalt and tar (as lumps, eg road planings, sealants)	Included in limit for other foreign material	10% in RCA(I)† or 5% in RCA(II)† or 10% in RCA(III)†	10%†
Wood (also any material less dense than water)	1% in RCA(I) or 0.5% in RCA(II) or 2.5% in RCA(III)§	Sub-base Types 1 and 2: 1% or CBM (1–5): 2%, and capping layer 6F1 and 6F2: 2%	2%
Glass	Included in limit for other foreign material	Contents above 5% to be documented	Contents above 5% to be documented
Other foreign material (eg metals, plastics, clay lumps)	5% in RCA(I) or 1% in RCA(II) or 5% in RCA(III)§	1% (by volume if ultra-lightweight)	1% (by volume if ultra-lightweight)
Sulfates	Concrete and CBM: 1% acid-soluble SO_3§. Unbound material: see Digest 363 if near concrete		

† No limit if physical and mechanical test criteria are satisfied.

§ RCA(III) must not replace more than 20% of natural aggregate. Limits on wood and other foreign matter assume that there will be no contribution from the natural aggregate. Similarly, a limit of 1% acid-soluble SO_3 should apply to 1:4 mixtures of RCA(III):natural aggregate.

Use of fine RCA in concrete

RCA passing a 5 mm sieve is not recommended for general use in concrete because it usually has an adverse effect on water demand and may contain increased levels of contamination. In specific circumstances where there is a high degree of control (eg fines from reclaimed product at a precast concrete works), 10% replacement of natural sand can be made without adverse effect on the product. Fine RCA may also be useful for large scale grouting operations (eg old tunnels and mine workings).

Handling difficulties may be experienced in conventional plant (eg sticking-up in hoppers). A partial removal of the finest fractions can provide a solution to this problem (see IP 14/98 on the production of blocks using RCA).

Recommended maximum grade of concrete

RCA(I): dry density < 2000 kg/m^3	C20
RCA(I): dry density > 2000 kg/m^3	C35
RCA(II)	C50
20% RCA(III) + 80% natural aggregate	no limit

Quality requirements in BS 882

These relate mainly to strength, shape, chloride content and general comments on suitability for particular purposes, and as such do not present compliance difficulties any more than for natural aggregates. The strength of RCA as measured by the '10% fines value' is normally in excess of 70 kN for Classes RCA(I) and (III) and 100 kN for Class RCA(II). Under normal circumstances the shape, as measured by the flakiness index, is well within acceptable limits. The chloride content is usually low but should be checked if the new concrete is to contain embedded metal. The BS 882 guidance for chloride in marine aggregates (related to overall limits given in BS 5328) should be applied; however it is advisable to determine acid-soluble chloride rather than water-soluble chloride unless research data on the long-term retention of chlorides in RCA becomes available.

Guidance on alkali silica reaction (ASR)

A large proportion of aggregates used in the UK are classed as 'normally reactive' (see Digest 330) and most sources of RCA would be expected to fall into the same classification. However, without more specific information on individual materials, it has been found necessary in Digest 330 to take a cautious approach and classify RCA as 'highly reactive'. The situation is complicated by the alkali contribution of the RCA to the new concrete, but the risk of expansion will be reduced by porosity in the RCA.

A calculation can be made according to Digest 330 taking into account the measured alkali content ($Na_2O + 0.658K_2O$) of the RCA. Alternatively, a quick check can be made using the following criteria:

If none of the source concrete has suffered expansion due to ASR, and ASR has not been suppressed by lack of moisture or by the 'pessimum' effect, the volume (V%) of crushed concrete in the new concrete should be estimated. This will normally be less than 50% for Class RCA(II) and 10% or less for Class RCA(III). Permitted alkali equivalent contents (kg/m^3) quoted in Digest 330 should then be reduced by a factor of V%.

The result of this is that in order to comply with guidance in Digest 330, high proportions of pfa or ground granulated blastfurnace slag will be required in most concretes containing Class RCA(II) crushed concrete coarse aggregate.

For the above calculation to be viable, some form of source or input control will be necessary for recycling plants. Such control also may assist in the declassification of the input material from 'highly reactive' to 'normally reactive'.

Limits on variability

For quality control of concrete, the dry density of delivered material should be kept to ±1% for Class RCA(II) and ±5% for Classes RCA(I) and (III).

Properties of concrete containing RCA

Due to the increased content of hardened cement paste in concrete containing RCA, elastic modulus will be reduced and shrinkage, creep and the coefficient of thermal expansion of the concrete will all be increased compared with similar strength concretes containing natural aggregates. For concretes containing Class RCA(III) aggregate which should replace only up to 20% of the coarse aggregate, the effect will be marginal; but for higher replacements, the effects may need to be taken into design considerations.

The literature on the frost resistance of concretes containing RCA indicates that there are no serious problems unless the source concrete had suffered frost damage due to non-durable aggregate. If fairly severe conditions of exposure for RCA concrete are being proposed, it will be prudent to carry out a freeze/thaw test; for example ASTM C666[3] on concrete specimens cast using the source of RCA proposed.

Test methods

Variations and additions to BS 812 which might be used for recycled aggregates are given below.

Composition

Using normal sampling procedures detailed in BS 812-101, a sample should be obtained of the aggregate containing at least 500 particles. The particles are then sorted manually into the following separate heaps:

- concrete and dense or normal weight aggregates;
- brick, mortar, lightweight block and lightweight aggregate;
- asphalt, bitumen, tar and mixtures of these materials with aggregate;
- wood;
- glass;
- other foreign material such as metals, clay lumps and plastics.

Because of the adherence of dust it may be necessary to wash or break some particles to make a positive identification. The resulting piles of material should be weighed and expressed as a percentage of the total weight of material.

Lightweight block materials

These should be noted as a separate category if more than 1% by volume (approximately 5 pieces in 500).

Presence of ultra-lightweight materials (eg insulation)

These should be noted if more than 0.5% by volume (ie more than 2 pieces in 500).

Gypsum plaster

Lumps of gypsum are normally pulverised by the crushing process and end up in the fine aggregate. The gypsum content is limited where required by an overall limit on sulphate (see Table 2).

Acid-soluble chloride and alkali content

Guidance is given in BS 1881-124.

Durability

BS 812-121 is inappropriate because of the reaction between magnesium sulfate and cement hydrates. If required, the following can be used:

- for frost heave of unbound mixtures – BS 812-124;
- for frost resistance of concrete containing RCA – method for concrete in BS 5075-2 or ASTM C666.

Quality control

The primary requirement for the provision of good quality products is input control for materials received at recycling plants. Each load of unprocessed material received at the plant should be inspected and, if accepted, placed on a stockpile designated for the quality of aggregate to be produced. The frequency of testing of the aggregate will depend on the quality of output required, but it will also depend on the quality of information on the input material. Although waste transfer notes and input inspection may suffice for the provision of reasonable quality materials in many cases, higher quality materials will benefit from the inspection of demolition sites and the preparation of deconstruction plans to maximise the usefulness of recovered material. Site inspections will also assist compliance with the Duty of Care regulations: contamination with industrial waste may have an effect on the setting of cement as well as on the contamination of groundwater (see IP 1/96).

Performance tests and requirements

Specifications based on product performance offer a more direct approach to assessing suitability for purpose than recipes of constituent materials. Standard specifications have traditionally been of the recipe type because they are normally easier to prepare and control. The tests in such specifications, however, are not always closely related to the required performance, and recipes may unnecessarily restrict the efficient use of resources. There is a long-term aim, expressed by the European Standard Committee for road materials (TC227), to develop performance based specifications. With such specifications, there should no longer be a focus on the constituent materials (whether recycled aggregate, industrial by-product or natural aggregate) but on the suitability of the material as a product for its proposed end use. Performance tests and requirements are already being used for mixtures of secondary materials: in particular, mixtures of concrete and bituminous material for use in road construction, and as hardcore.

References

[1] Department of Transport et al. *Manual of contract documents for highway works.* Volume 1, Specification for highway works. London, HMSO, 1991.

[2] The Highways Agency et al. *Design manual for roads and bridges. Conservation and the use of reclaimed materials in road construction and maintenance.* Volume 7, Section 1. Technical Memorandum HD35/95. London, The Highways Agency, 1995.

[3] American Society for Testing and Materials. Annual book of ASTM standards: Part 14, Concrete and mineral aggregates. Philadelphia, ASTM.

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Efficient use of aggregates and bulk construction materials. Volume 2: Technical data and results of surveys. BR 244.

BRE Information Papers

5/94 The use of recycled aggregates in concrete
1/96 Management of construction and demolition wastes
3/97 Demonstration of reuse and recycling of materials: BRE energy efficient office of the future
14/98 Blocks with recycled aggregate: beam-and-block floors

Other BRE Digests

276 Hardcore
330 Alkali-silica reaction in concrete, Parts 1–4
363 Sulfate and acid resistance of concrete in the ground

British Standards Institution

BS 812:1984–95 Testing aggregates
BS 882:1992 Specification for aggregates from natural sources for concrete
BS 1047:1983 Specification for air-cooled blastfurnace slag aggregate for use in construction
BS 1881-124:1988 Testing concrete. Methods for analysis of hardened concrete
BS 3797:1990 Specification for lightweight aggregates for masonry units and structural concrete
BS 5075-2:1982 Concrete admixtures. Specification for air-entraining admixtures
BS 5328:1990–97 Concrete
BS 6543:1985 Guide to use of industrial by-products and waste materials in building and civil engineering

Further reading

Collins R J and Sherwood P T. *Use of waste and recycled materials as aggregates: standards and specifications.* London, HMSO, 1995.

Soils and Materials Design and Specification Group, County Surveyors' Society Engineering Committee. *Use of recycling for road pavement construction and maintenance.* Report ENG/1-94. Dorchester, County Surveyors Society Engineering Committee, 1994.

BRE. *Efficient use of aggregates and bulk construction materials.* Volume 1: An overview. BRE Report BR 243. Garston, CRC Ltd, 1993.

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Fax 01923 664098

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