Design Manual for Roads and Bridges

Highway Structures & Bridges
Design

CD 374
The use of recycled aggregates in structural concrete

(formerly BA 92/07)

Revision 0

Summary
This document enables the use of recycled aggregates in structural concrete for highways structures, providing key information that is required to design structural concrete containing recycled aggregates and manage the risks in their adoption.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

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Release notes

Version	Date	Details of amendments
0	Mar 2020	CD 374 replaces BA 92/07. This full document has been re-written to make it compliant with the new Highways England drafting rules. This includes removal of information that is covered in other industry guidance.

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Foreword

Publishing information

This document is published by Highways England.

This document supersedes BA 92/07, which is withdrawn.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

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Introduction

Background

This document gives requirements and advice for the use of recycled aggregates in structural concrete for highways structures, providing key information that is required to design structural concrete containing recycled aggregates and manage the risks in their adoption.

Recycled aggregates, as opposed to natural and manufactured aggregates that are of mineral origin, result from the processing of inorganic material previously used in construction and can be made of different constituents, defined in BS EN 12620 [Ref 1.N] as:

1) Rc (concrete, concrete products, mortar, concrete masonry units);
2) Ru (unbound aggregate, natural stone, hydraulically bound aggregate);
3) Rb (clay masonry units such as bricks and tiles, calcium silicate masonry units, aerated non-floating concrete);
4) Ra (bituminous material);
5) FL (floating material in volume);
6) Rg (glass);
7) X (other - cohesive clay or soil, ferrous or non ferrous metals, non-floating wood, plastic, rubber, gypsum plaster).

Aggregates for concrete, including recycled aggregates, are covered in BS EN 12620 [Ref 1.N] which gives, as one of the essential characteristics, the composition of coarse recycled aggregates in terms of categories of content for each constituent.

This document clarifies that the performance requirements for recycled aggregates to be used for highway structures, including their composition, are those given in BS 8500-1 [Ref 4.N] and BS 8500-2 [Ref 5.N].

This document sets out the considerations a designer should take into account for using recycled aggregates in highways structures. It also sets out the limitations on where these should be used and describes the effects on concrete properties.

The document is also intended to summarise the provisions of the standards and documents relevant to the use of recycled aggregates in the UK. Since the publication of the previous edition, a number of those have been published or updated, updated, allowing the streamlining of the requirements and advice and refer, where appropriate, directly to those.

Relevant standards and documents include BS EN 12620 [Ref 1.N] and the associated PD 6682-1 [Ref 10.N], BS EN 206 [Ref 3.N] and the complementary British Standards BS 8500-1 [Ref 4.N] and BS 8500-2 [Ref 5.N], and MCHW Series 1700 [Ref 9.N].

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 8.N] apply to this document.

Mutual Recognition

Where there is a requirement in this document for compliance with any part of a "British Standard", or other technical specification, that requirement may be met by compliance with GG 101 [Ref 8.N].

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Abbreviations and symbols

Abbreviations

Abbreviation	Definition
ASR	Alkali silica reaction
CCA	Crushed concrete aggregate
GGBS	Ground granulated blast furnace slag
IDC	Internal degradation of concrete
WRAP	Waste and resource action programme

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Terms and definitions

Terms and definitions

Term	Definition
Alkali aggregate reaction	Damaging chemical reactions to aggregates within a mass of concrete which can include alkali silica reaction, alkali silicate reaction or alkali carbonate reaction. Alkali silica reaction (ASR) is the most common.
Crushed concrete aggregate	Recycled aggregate obtained from crushed concrete.
Internal degradation of concrete	Deterioration mechanism (consisting of alkali aggregate reaction or delayed ettringite formation) which affects the concrete composition and can affect concrete mechanical properties. Concrete degradation factors define the degradation of mechanical properties.
Manufactured aggregate	Aggregate of mineral origin resulting from an industrial process involving thermal or other modification.
Natural aggregate	Aggregate from mineral sources which has been subjected to nothing more than mechanical processing.
Recycled aggregate	Aggregate resulting from the processing of inorganic material previously used in construction.

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1. Scope

Aspects covered

1.1 The requirements set out in this document shall be adopted for the use of recycled aggregates in structural concrete for highway structures.

NOTE 1 *The use of recycled aggregates in structural concrete is encouraged, as it can provide benefits associated with sustainable development, related to prudent use of natural resources and maximising use of recycling of construction waste, and potential for cost savings; however, while their use is well established for low grade applications such as sub base in road construction, use in structural concrete applications has been limited.*

NOTE 2 *An inherit characteristic of recycled aggregates is that they have a higher water demand than aggregates of mineral origin, which could lead to reductions in strength and durability performance of the hardened concrete. For this reason, they are generally used only in combination with natural and manufactured aggregates within a concrete mix.*

NOTE 3 *Until a track record of successful use of recycled aggregates in structural concrete is established, their use is restricted to structural elements subject to less onerous exposure classes and with inherent robustness.*

Implementation

1.2 This document shall be implemented forthwith on all schemes involving the use of recycled aggregates on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 8.N].

Use of GG 101

1.3 The requirements contained in GG 101 [Ref 8.N] shall be followed in respect of activities covered by this document.

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2. Recycled aggregate

Supply

2.1 Recycled aggregates for use in structural concrete shall be specified to conform to BS EN 12620 [Ref 1.N].

NOTE *PD 6682-1 [Ref 10.N] gives guidance on the use of BS EN 12620 [Ref 1.N] and recommends the limiting values of aggregate properties for use in the UK within the permitted range.*

2.2 When coarse recycled aggregates are used, the performance requirements of the aggregates in relation to the essential characteristics in BS EN 12620 [Ref 1.N], including the composition in terms of categories of content of constituents of recycled aggregates, shall be as those given in BS 8500-2 [Ref 5.N] for coarse crushed concrete aggregates (CCA).

NOTE 1 *Definitions and distinction between coarse and fine aggregates are given in BS EN 12620 [Ref 1.N].*

NOTE 2 *The performance requirements given in BS 8500-2 [Ref 5.N] for coarse CCA in terms of category of content of constituents ensure that the coarse recycled aggregates are adequate for use in structural concrete.*

NOTE 3 *The use of fine recycled aggregates in structural concrete applications is not recommended, as there are challenges in establishing their suitability, as clarified in BS 8500-1 [Ref 4.N] and BS 8500-2 [Ref 5.N].*

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3. Structural concrete incorporating recycled aggregates

Design

3.1 Design of structural concrete incorporating recycled aggregates, undertaken to BS EN 1992-1-1 [Ref 7.N] and BS EN 1992-2 [Ref 6.N], shall take into account the changes in properties of fresh and hardened concrete resulting from the presence of recycled aggregates in the concrete mix.

NOTE *Mix design of concrete incorporating recycled aggregates is a specialist skill to be undertaken by personnel with the appropriate knowledge and experience.*

3.1.1 The magnitude and significance of changes in the properties of concrete, due to the use of recycled aggregates, which could affect the design of the structural concrete element should be assessed.

NOTE 1 *Incorporating recycled aggregates into concrete can have an effect on the concrete properties, and as the amount of recycled aggregates increases the changes become more pronounced. This can lead to changes in physical properties of the concrete and potential effects on durability.*

NOTE 2 *Guidance on properties of recycled aggregates and their effect on structural concrete is provided in Appendix A.*

3.1.2 For non-prestressed concrete, where the proposed percentage of recycled aggregates exceeds 30% of the total aggregates by mass in the concrete mix, the modulus of elasticity of the concrete should be a measured value from trial concrete mixes and not values based on cube strength (as is often used for normal concrete), as the relationship between cube strength and modulus can be different.

NOTE *BS EN 1992-1-1 [Ref 7.N] clarifies that the modulus of elasticity of a concrete is controlled by the modulus of elasticity of its components, which is largely dictated by the aggregates.*

3.1.3 For prestressed concrete, the modulus of elasticity should be measured from trial concrete mixes in all cases.

3.1.4 BS EN 1992-1-1 [Ref 7.N] gives guidance on shrinkage and creep for normal concrete and this may need to be adjusted to suit the properties of the concrete mix incorporating recycled aggregates on the basis of the results from trial concrete mixes.

Limitations to use

3.2 The percentage of recycled aggregates to the total aggregates by mass in the concrete mix shall not exceed:

1) 60% for non-prestressed concrete structures;
2) 20% for prestressed concrete structures.

NOTE 1 *The effect on concrete properties when high percentages of recycled aggregates are used can be considerable and it is not considered appropriate at this stage for this percentage to exceed 60%.*

NOTE 2 *The 20% limit on percentage of recycled aggregates to the total aggregates by mass in the concrete mix for use in prestressed concrete is in relation to the increasingly higher effects on drying shrinkage and potential effects on creep on concrete incorporating recycled aggregates beyond that level, which are considered to give too high an unknown for the long-term properties of prestressed concrete.*

3.2.1 When the proposed percentage of recycled aggregates to the total aggregates by mass in the concrete mix in non-prestressed concrete structures is in excess of 30%, and in all cases for prestressed concrete structures, trial mixes should be specified at an early stage on the proposed resulting concrete to verify the properties to be used in design, to be subsequently agreed as part of the technical approval process to CG 300 [Ref 11.N].

3.2.2 For buried structures and structures with no access for inspection, the percentage of recycled aggregates to the total aggregates by mass in the concrete mix should not be in excess of 30%.

NOTE 1 *A percentage of recycled aggregates of up to 30% of the total aggregate by mass in structural concrete is recommended as the limit in BS EN 206 [Ref 3.N] for typical exposure classes; up to this level the*

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impact on the design properties for non-prestressed concrete is considered minimal and no additional measures need to be undertaken..

NOTE 2 *Guidance on the properties of structural concrete incorporating recycled aggregates that could affect the design considerations is given in Appendix A.*

3.3 Structural concrete incorporating recycled aggregates shall not be used for structures in exposure classes other than X0, XC1, XC2, XC3, XC4, XF1, XD1 and DC-1.

NOTE 1 *The exposure classes for structural concrete for use in the UK are defined in BS 8500-1 [Ref 4.N].*

NOTE 2 *The limitations for use in relation to the exposure classes are those recommended in BS EN 206 [Ref 3.N], which differ to those in BS 8500-2 [Ref 5.N] insofar that the latter does not routinely allow use of recycled aggregates in structural concrete for exposure class XD1.*

NOTE 3 *BS 8500-2 [Ref 5.N] permits the use of recycled aggregates in structural concrete to all exposure classes if it is demonstrated that the resulting concrete is suitable for the particular exposure, arguably by satisfactory past performance, incorporation of special protective measures or by a specific mix design, supported by adequate test evidence, to address the relevant durability concern.*

3.4 Structural concrete incorporating recycled aggregates shall only be used for strength classes up to C40/50 as per the recommendations in BS 8500-2 [Ref 5.N], unless the recycled aggregates is obtained by crushing hardened concrete of known composition that has not been in use, e.g. surplus precast units or returned fresh concrete, and not contaminated by storage or processing.

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4. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	BSI. BS EN 12620, 'Aggregates for concrete'
Ref 2.N	Highways England. CG 302, 'As-built, operational and maintenance records for highway structures'
Ref 3.N	BSI. BS EN 206, 'Concrete - specification, performance, production and conformity '
Ref 4.N	BSI. BS 8500-1, 'Concrete. Complementary British Standard to BS EN 206. Method of specifying and guidance for the specifier.'
Ref 5.N	BSI. BS 8500-2, 'Concrete. Complementary British Standard to BS EN 206. Specification for constituent materials and concrete.'
Ref 6.N	BSI. BS EN 1992-2, 'Eurocode 2. Design of concrete structures. Part 2: Concrete bridges. Design and detailing rules'
Ref 7.N	BSI. BS EN 1992-1-1, 'Eurocode 2: Design of concrete structures. General rules and rules for buildings'
Ref 8.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 9.N	Highways England. MCHW Series 1700, 'Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works - Series 1700 Structural Concrete'
Ref 10.N	BSI. BSI. PD 6682-1, 'PD 6682-1 Aggregates - Part 1: Aggregates for concrete - Guidance on the use of BS EN 12620 - AMD: May 2013 '
Ref 11.N	Highways England. CG 300, 'Technical approval of highway structures'

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5. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	WRAP. WRAP (2013), 'WRAP Quality Protocol: Aggregates from inert waste, End of waste criteria for the production and use of aggregates from inert waste'

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Appendix A. Properties of recycled aggregate and its effect on structural concrete

A1 Properties of recycled aggregate

Particles of recycled aggregate generally comprises crushed stone aggregate partially coated with mortar or cement paste. The amount of surrounding mortar will vary depending on the method by which the recycled aggregate was produced; for example, an increasing number of cycles in a ball crusher can reduce the amount of mortar present. However there are other more efficient processing methods available, but the aim should still be to remove as much of the mortar as possible. The mortar, which is lighter and more porous than aggregates used in standard concrete mixes, affects the physical properties of the recycled material notably with respect to water absorption and density. This has implications for concrete mix design and concrete properties such as elastic modulus, shrinkage, creep and permeability. Moreover, the increased alkali content resulting from the mortar, and the presence of unknown aggregate types in the parent concrete of the recycled aggregate might increase the risk of internal degradation of concrete (IDC). The parent concrete could also have additional contaminants such as high chloride levels, carbonated material or IDC reaction products. In fact such features might be the reason for the concrete to have been recycled in the first place.

A2 Internal degradation of concrete (IDC)

IDC needs greater consideration where recycled aggregates are used. The mortar surrounding the aggregate particles will increase alkali levels and there is the possibility that the source concrete for the recycled aggregate included reactive aggregates, although the risk of expansion would be reduced because of the higher porosity of recycled aggregate. If the specification for the original source concrete is known then the aggregate reactivity could be assessed but this will not always be the case. There is also the possibility that partial replacement with recycled aggregate could result in pessimum proportions – the concentration of reactive aggregates where the reaction is maximised. If it is known that active IDC or significant quantities of IDC were present in a source structure this would preclude its use as a source of recycled aggregate. Moreover, if there is any reason to believe that there might be reactive aggregates in the recycled aggregate, a petrographical examination may be carried out or the recycled aggregate classed as high reactivity for the purpose of checking the susceptibility of the resulting concrete to ASR.

A3 Properties of structural concrete incorporating recycled aggregates

A3.1 Physical properties

The impact of the following on physical properties on the concrete should be accounted for in the development of a mix design for structural concrete incorporating recycled aggregates, which are areas where there are likely to be differences compared with similar strength concretes made with traditional aggregates:

1) water demand (in the fresh state) increases with increase in recycled aggregate content, where the degree of demand increases as the proportion of recycled aggregate increases;
2) density is reduced, where the degree of reduction increases as the proportion of recycled aggregate increases;
3) modulus of elasticity is reduced, where the degree of reduction increases as the proportion of recycled aggregate increases;
4) shrinkage is increased, where increasing levels of recycled aggregate lead to increased shrinkage and potential problems with creep, especially relevant for prestressed concrete;
5) permeability is increased, which could result in more rapid ingress of contaminants;
6) potential impacts on other concrete properties include coefficient of thermal expansion, tensile strength, and bond strength;
7) the cement content of the mix containing the recycled aggregate and its effect on various properties of concrete.

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As the information available on the degree of such effects is not extensive, it is prudent to adopt a conservative approach to the use of recycled aggregate in structural concrete, which results in its use not being recommended for high percentage of replacement, especially in more sensitive cases such as prestressed concrete, concrete structures difficult to inspect and high strength concrete applications with higher degrees of doubt about the condition of the source concrete of the recycled aggregates.

A3.2 Effects on durability

The impact of the following on durability of the concrete should be accounted for in the development of a mix design for structural concrete incorporating recycled aggregates, which are areas where there are likely to be differences compared with similar strength concretes made with traditional aggregates:

1) there are no indications that freeze thaw resistance and resistance to carbonation are particularly different, provided that properly quality controlled recycled aggregate has been used;
2) the increased permeability of concrete incorporating recycled aggregate can increase the rate of chloride ingress and may lead to higher corrosion rates; however the increased alkali content of recycled aggregate could assist in raising the chloride threshold level which triggers corrosion, and the use of blended cements with higher proportions of additions such as GGBS or fly ash may greatly mitigate the effects;
3) sulfate attack can result in expansive disruption of concrete. In some cases sulfate contamination could be present in recycled aggregate (e.g. from plaster), and this should be taken into account in choosing source material for the recycled aggregate. There are no indications that resistance to external sources of sulfate would be dissimilar to traditional aggregate concrete;
4) alkali silica reaction and, more generally IDC, needs greater consideration, as described in section A2 of this Appendix.

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Appendix B. Guidance for the specification

B1 General

The use of structural concrete incorporating recycled aggregates is not covered by the MCHW Series 1700 [Ref 9.N] , and its specification is subject to a Departure from Standard until such time when its use becomes more established and will be included in the MCHW Series 1700 [Ref 9.N].

MCHW Series 1700 [Ref 9.N] requires that structural concrete is a designed concrete compliant with the requirements of BS EN 206 [Ref 3.N], BS 8500-1 [Ref 4.N] and BS 8500-2 [Ref 5.N].

For the use of structural concrete incorporating recycled aggregates it is necessary to provide additions and modifications, where appropriate, to the provisions of MCHW Series 1700 [Ref 9.N] to cover some specific aspects related to the specification of recycled aggregate itself and the implications for the structural concrete incorporating it.

In particular, amendments are required to the provisions of Clause 1702 of MCHW Series 1700 [Ref 9.N] (and its accompanying NG) with respect to requirements and guidance for the supply of recycled aggregates to BS EN 12620 [Ref 1.N], including the performance requirements and provisions for testing their acid-soluble sulfate and chloride content; expectations for quality control; the proposed percentage of recycled aggregates compared to to total aggregates by mass in the concrete mix, also in relation to the limitations on concrete strength and exposure classes; and the use of blended cements.

Expectations for quality control include recommending recycled aggregates to be obtained from producers who comply with the principles of the WRAP (2013) [Ref 1.I] Quality Protocol. WRAP (2013) [Ref 1.I] indicates how compliance is demonstrated by producers, also in terms of waste acceptance; sets out end of waste criteria whose compliance is considered sufficient to ensure that the fully recovered product can be used without the need for waste management controls; and points to good practice for storage, transportation and handling of the fully recovered product.

Amendments are required to the provisions of Clause 1704 of MCHW Series 1700 [Ref 9.N] (and its accompanying NG) with respect to requirements and guidance on total chloride and sulfate content of the concrete, and the control of alkali silica reaction of the concrete incorporating recycled aggregates.

Amendments to the provisions of Clauses 1707 and 1708 of MCHW Series 1700 [Ref 9.N] (and their accompanying NG) may be required with respect to requirements and guidance on conformity and identity testing for trial mixes of concrete incorporating recycled aggregates, and for trial panels to check surface finishes.

Specific provisions for structural concrete containing recycled aggregates may be included in contract specific Appendices 17/1, 17/3 and 17/4 of the MCHW Series 1700 [Ref 9.N].

It is expected that a record giving supply details and test results is kept for each delivery of recycled aggregates from the source to the processing plant, cross referenced with the source material and including reference to any particular issues such as chloride contamination or IDC in specific elements, and that a record giving test results on trial mixes of the concrete mix containing recycled aggregates is kept; both records to be subsequently supplied to the Overseeing Organisation in accordance with the requirements of CG 302 [Ref 2.N].

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Notification

This document was notified in draft to the European Commission in accordance with Technical Standards and Regulations Directive 2015/1535/EU.

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