Guide Specification

Recycled glass as sand replacement in premix concrete

EcoRecycle Victoria
ACI Glass Packaging Australia
Alex Fraser Recycling Industries Pty Ltd
CSIRO

by

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Table of Contents

		Page No
∉	**Executive Summary**	6
∉	**Introduction**	7
1.0	**General Background**	7
1.1	Glass Cullet as a Construction Material	7
1.2	Cullet Applications in Construction	8
1.3	Overview of Guide Specifications and Commentary	9
2.0	**Model Specifications For Recycled Glass As Construction Aggregate**	10
2.1	Scope	11
2.2	Quality Systems	12
2.3	Definitions	12
2.4	Recycled Cullet Concrete (RCC) Classification	12
2.5	Guide Specifications for Crushed Cullet Sand (CCS)	13
2.5.1	Graded cullet sand	13
2.5.2	Grading	13
2.5.3	Bulk density	13
2.5.4	Foreign materials content	13
2.5.5	Durability	13
2.5.6	Absorption and moisture content	13
2.5.7	Contaminants	14
2.5.8	Alkali-Silica Reaction (ASR)	14
2.6	Cement and Admixtures	14
3.0	**Guide to the Specification of Recycled Cullet Concrete (RCC)**	15
4.0	**Background and Commentary on Model Specification**	17
4.1	Glass Cullet Aggregate	17
4.2	Feedstock Preparation	17
4.3	Cullet Crushing	17
4.4	Cullet Feedstock	18
4.5	Physical Properties of Cullet	19
4.6	Typical Contaminants in Recycled Glass	19
4.7	Durability	20
4.8	Chemical Composition and Glass Types	20
4.9	Water Absorption	22
4.10	Chemical Contaminants	22
4.11	Processing and Mixing	22
4.12	Safety	23
4.13	Glass Aggregate Dust	23
4.14	Preliminary Laboratory Trials	25
4.15	Compressive Strength	26
4.16	Drying Shrinkage	28
4.17	Alkali-Silica Reactivity (ASR)	29
4.18	Comments on ASR	33
5.0	**Commentary on Model Specification**	**34**
5.1	Glass Cullet Concrete Production	35
6.0	**Field Trial and Commentary on Concrete Production**	**36**

EXECUTIVE SUMMARY

This document compiles draft specifications for utilising glass cullet as fine sand replacement in premix concrete based on laboratory and field data. Commentary on various aspects of field performance of glass cullet concrete is also provided. With the move towards performance based specifications, typified by AS 3600, i.e. fitness for purpose rather that conventional prescriptive specifications, it is anticipated that restrictions on cullet content in new concrete will be confined to situations where limited technical data exists to support field performance. The summary and recommendations on the findings of the project are briefly outlined below.

1. Based on conventional concrete practice, test data suggest that the minus 2.46mm size fraction of crushed cullet has a grain size close to that of fine sand and can perform well in premix concrete if appropriately blended with natural sand.

2. Within the scope of this study, satisfactory concrete performance was achieved in both laboratory and field tests on premix concrete incorporating cullet sand.

3. Cullet specifications may require that the processed glass be blended with natural sand to specified percentages depending on type and nature of application. A 20% cullet replacement limit is recommended for non-structural concrete.

4. Alkali-silica reactivity arising from cullet use as fine sand replacement can be significantly minimised with the use of binders containing 30% or more Class F Fly ash.

5. There is a corresponding 5% reduction in concrete compressive strength at 5% cullet substitution for natural sand in concrete compared to a 27% reduction at 30% glass substitution level.

6. Marginally lower drying shrinkage values are obtained for glass cullet concrete compared to equivalent conventional concrete mixes.

7. Results of the study should increase the confidence of practitioners to specify recycled glass aggregate in municipal construction projects, such as footpaths, and cycle ways.

<u>Recommendations</u>

- Future developments regarding construction with secondary materials should focus on the need for standards that ensure compliance to performance and safety requirements of the building and construction industry.

- It appears that architects, builders, engineers, purchasing agents and others in the building/construction industry would be more inclined to consider recycled-content building materials if they knew more about the quality, performance and availability of these products, as well as opportunities and strategies for overcoming any possible obstacles to their use.

- On going seminars would serve as a forum for interactive dialogue where, regulators, policy makers, construction practitioners, recyclers and current and potential users of recycled products such as cullet concrete could share their experiences with those who may be interested in considering their use.

Introduction

This manual provides specification information and commentary on the use of cullet as a construction material. It combines laboratory research, previously reported in CSIRO DBCE Doc #00/079, with field performance data to assess specification requirements of recycled glass as partial fine aggregate replacement in premix concrete production. Within this scope also fall other potential uses for colour-mixed or sorted glass cullet, particularly where construction specifications can be created alongside reliable supplies to ensure economic viability. The scope of this guide specification is however limited to technical requirements, including commentary, on the use of glass cullet as sand replacement in premix concrete production. The project was carried out in collaboration with ACI Glass Packaging Australia and Alex Fraser Ltd with support from EcoRecycle Victoria under Grant No 1230.

The document is the first step towards development of a comprehensive standard that would provide guidance on glass cullet requirements in construction, to material specifiers, suppliers and potential end-users. It further provides regulators, recyclers and MRF operators, local government and other stakeholders with technical information on ways to better manage and use glass cullet and other secondary resources. To achieve this goal requires regions with relatively low glass-generation rates, such as small communities, where stockpiles of sufficient size need to be accumulated to provide a consistent supply of material in order for glass cullet to be considered for practical applications in construction.

Data for the development of this guide specification has been generated mainly from short-term laboratory testing and field trials of pre-mix concrete incorporating up to 20% percent crushed glass replacement for the fine sand component of the concrete. The development of suitable formal specifications should, however, be based on extensive laboratory tests refined by field performance and durability data. While the document also highlights related opportunities for using glass cullet in other building products, it does not cover technical requirements for such applications. The document is intended to serve only as a guide and is not produced for use in place of tender specifications.

1.0 General Background

1.1 Glass cullet as a construction material

There exist a wide variety of recycled materials that can be used in construction. It is however also widely recognized that increased use of these materials in construction is critical to national efforts to expand markets for recyclables. Thus, for economic and environmental reasons including the drive towards sustainable construction, both government and various industry sectors are beginning to develop and establish alternative markets for recycled construction products derived from waste brick and tile, concrete and plastic feedstock.

By contrast, direct use of recycled glass in construction is relatively new. While most communities are making the decision to process collected recycled glass locally in order to develop local recycled glass self-reliance, the development of appropriate products and markets matched by suitable specifications appears to be progressing at a much slower pace.

Several opportunities exist for using glass cullet in building product manufacture and in civil construction. For concreting applications, some key considerations for using glass cullet may be its lower cost due to ready availability, the desire to alter surface texture of concrete, increased wearability of the concrete surface by adding a harder aggregate, or improvement of the aesthetics of the surface by adding coloured aggregate.

In recent years, crushed, graded recycled glass has been extensively researched and trialed as aggregate substitute in a number of other construction related applications. The critical requirement in all these applications is that the correct characteristics and physical properties of the glass aggregate for the target application are well understood and defined.

1.2 Cullet applications in construction

1.2.1 Overview of cullet as fine sand replacement in premix concrete

Waste glass that is crushed and screened has the potential for use as sand substitute in concrete. In many respects, glass that has been reduced to a fine aggregate size fraction (minus 2.46 mm grading) exhibits physical properties similar to that of a fine aggregate or sandy material.

Satisfactory performance has been obtained in laboratory test and field premix concrete trials incorporating up to 20% percent crushed glass as fine sand replacement.

Most current standards or specifications for building materials specify performance standards, rather than identifying specific acceptable materials i.e. prescriptive material-based standards, for various uses. Therefore, there exist generalized circumstances for which recycled materials could be used for non-load bearing applications where performance could be deemed acceptable and for uses where health and safety requirements are met.

Restrictions on products manufactured with 100% virgin materials apply equally to equivalent products containing recycled materials. In the absence of appropriate codes, it is recommended that the use of aggregates from glass be considered on a project-by-project basis only.

1.2.2 Uses for glass cullet in construction

The use of mixed glass cullet as aggregate for premix concrete production, and for fill and drainage applications is still being widely researched. In addition, other potential construction applications identified for recycled glass include:

- General backfill and utility construction: Varying levels of cullet up to 100% proposed for general backfill applications such as underground facilities, trenches utility bedding, and landfill applications.
- Aggregate substitute; container and non-container glass utilised in concrete, road beds, pavement and parking lots, as well as drainage medium, backfill or landscaping purposes and roadway construction.
- Filtration and drainage applications in foundations and retaining walls and high rate filtration media.
- Landfill cover, topsoil blend and underground storage tank backfill material.

1.2.3 General uses of glass cullet

Several potential products and markets have been researched including:

- Abrasives: Finely ground container and non-container glass that can be used in sandblasting.
- Fluxes/additives: Glass powders used as lubricants, core additives and fluxes in metal foundry work and fabrication, as well as flux in the ceramics industry.
- Architectural applications including glass bricks and paving blocks.
- Fiberglass insulation and glass foam insulating products.

1.3 Overview of Guide Specifications and Commentary

The criteria for developing specifications for any aggregate rely on a combination of technical data and practical historical experience. Currently, the availability of detailed performance and durability data for glass aggregates as concrete sand is limited. This lack of information poses a barrier to wide spread use of the material. However, there appears to be sufficient local and overseas data generated from on-going research and field trials to develop preliminary model product specifications for cullet as fine sand replacement in concrete production.

Given these limitations of the guide specification, It is essential that for every construction project, the use of cullet aggregate should be discussed among engineers, contractors, earthwork sub-contractor, foremen, owners and concreters to confirm material suitability for the intended purpose.

Furthermore, the advantages and disadvantages of using cullet as a construction aggregate and the awareness of the rationale for using such a new construction material needs to be demonstrated at all levels of construction including strategies to facilitate the cost-effective use of such materials. This effort largely depends on future development of appropriate standards for manufacturing and product performance to facilitate material specification and ensure consumer acceptance.

General Specifications requirements

For the purpose of this document, glass aggregate sand typically implies a blend of glass and natural fine sand for use in premix concrete production. For general applications, specifications regarding cullet content, grading, debris level, physical and mechanical properties and performance requirements of the in-place material are essential and must be especially well understood.

It is further important to base specifications for individual projects on local variables such as soil and exposure conditions, and type of construction works.

Although glass has been used in aesthetic applications in conventional concrete for many years, research is not yet conclusive enough to fully recommend its use in structural concrete applications.

2.0 MODEL SPECIFICATIONS FOR RECYCLED GLASS AS CONSTRUCTION AGGREGATE

Theoretically, both secondary and virgin materials have equal chance for acceptance in most performance-based codes since these standards are based on their relative performance rather than prescriptive material properties. In this regard, suppliers of secondary materials have to ensure that materials consistently meet the performance and safety requirements of the building and construction industry.

Typically, such performance specifications are derived from extensive product testing and well-proven performance criteria related to the engineering behaviour of the in-place material. It is therefore important for concrete applications of cullet that, the behaviour and properties of the final product are validated before specification.

The industry and regulators must also ensure the health and safety requirements of the public are met to the extent that recycled cullet aggregate does not only remain technically viable but a safe and cost-effective product for nominated end-uses.

Random batches of cullet representing typical material derived from MRF facilities were used in the laboratory evaluation study program. A range of laboratory tests as per AS 1141 and AS 2758(Aggregates and rock for Engineering Purposes) were conducted on batch samples, including material grading, particle shape, texture, glass type and composition characteristics. Data generated from sample characterisation formed the basis for material performance assessment during the construction applications testing program.

Results of related projects on glass cullet applications from ongoing research on the use of micro-fine glass as a cement substitute and investigations involving potential alkali silica reactivity of glass cullet in Portland cement based products have also become available.

Relevant Australian Standard[AS]

1. AS 1012-1997 Methods of testing concrete
2. AS 1141.3.1 -1996: Sampling of aggregates
3. AS 1141.4 -1996: Bulk density of aggregates
4. AS 1141.6.2 -1996: Particle density and water absorption of aggregates
5. AS 1141.11 -1996: Particle size distribution by dry sieving
6. AS 1141.21 -1997: Aggregate crushing value
7. AS 1379 - 1997: The specification and manufacture of concrete
8. AS 2758.1 - 1985 Concrete Aggregates
9. AS 3600 -1994: Concrete Structures
10. AS 3972 Portland and Blended cements
11. AS 3727 Guide to residential Pavements
12. AS/NZS ISO 9002 Quality systems-model for quality assurance in production, installation and servicing

2.1 Scope

This guide specification sets out some preliminary requirements for material quality, supply, and the placement and curing of concrete incorporating glass cullet as partial sand substitute for municipal and building construction works. Such works include cycleways, footpaths, kerb and gutter and related non-structural concrete construction.

2.1.1 Some essential material properties for successful specification of recycled glass cullet in pre-mix concrete production. Thus, this guide is intended to aid quality control and utilisation of **2.46mm minus sieve size crushed cullet as partial sand replacement** in plain and reinforced non-structural concrete construction applications.

2.1.2 Some general guidelines are set for quality acceptance and allowable contaminant limits. Methods of cullet production and procedures covering concrete batching are not covered in this document. However, an attempt is made to highlight known limitations, advantages and changes in fresh and hardened concrete performance that arises with partial replacement of natural sand with crushed cullet.

2.1.3 The outlined technical information only applies to crushed cullet fines in the nominated size range, produced from clean uncontaminated recycled glass.

2.1.4 For concrete production, the specifier is responsible for selecting and proportioning the concrete mixture and shall have the responsibility of determining nominal aggregate size and grading requirements in addition to the blending of aggregate sizes if so required.

2.1.5 The current model specifications have been developed based largely on material behaviours tested in the laboratory. These specifications are conservative in terms of the types of cullet and debris allowed, and substitution required. General quality control measures and grading requirements applicable to glass aggregate have also been defined.

2.1.6 Codes that are materials-based, i.e., prescriptive codes, generally require approval of materials used in construction, but often do not specifically exclude recycled-content materials, provided that such materials meet specified performance standards. In reality, however, there are specific performance standards, which present barriers to the recycled-content products.

2.1.7 The material behaviour of cullet sand blends is similar to those of natural sand, and thus the criteria for specifications should be relatively similar to those of natural materials. However, because cullet blend is a relatively new construction material, the performance of glass aggregate in construction applications may draw more scrutiny than expected for customary materials.

2.2 Quality Systems

A manufacturing plant, which is operating under a quality assurance system, preferably one that satisfies the requirements of ISO 9002, shall produce concrete. The Contractor should meet test report requirements and production assessment reports as required by the Superintendent.

2.3 Definitions

This Guide applies similar definitions as in Australian Standards regarding manufacture and testing of aggregate and concrete except in situations where specific amendments are detailed.

2.3.1 *Crushed Cullet Sand(CCS)*– Uniformly graded fine sand aggregate blend(2.46mm minus), produced by blending a maximum of 20% by weight of crushed cullet glass and natural fine sand. The total contaminant levels of the cullet sand material other than clean recycled cullet should typically be lower than 2% of the bulk mass. The material shall consist primarily of glass, and should conform to the specification outlined in this guideline.

2.3.2 *Recycled Cullet Concrete(RCC)* - Concrete produced with partial replacement of fine sand aggregate fraction with graded crushed cullet and natural sand as coarse aggregate.

2.3.3 *Natural Aggregates*– Standard natural or manufactured coarse aggregates normally used in conventional pre-mix concrete.

2.3.4 *Natural Aggregate Concrete* – Concrete produced with gravel or crushed rock as coarse aggregate and natural sand as fine aggregate.

2.3.5 *Recycled Glass* – Sorted and clean **container glass** generated from MRF's and kerbside collection for the purpose of crushing and grading to produce uniform quality RCC.

2.3.6 *Contaminants* – Impurities typically associated with container glass such as Pyrex, drinking glass, ceramics, plastic and metal bottle caps, lids, bottleneck rings etc.

2.4 Recycled Cullet Concrete(RCC) Classification

2.4.1 Only one class of crushed cullet sand(CCS) is considered in this model specification. This classification does not however preclude addition of new classes of material once sufficient technical data on material characteristics have been generated.

2.4.2 *Class 1 Clean Recycled Cullet Sand – (Particle density >1800 kg/m^3):* Crushed cullet sand produced from quality uniform glass feedstock stock of no more than 2% contaminants manufactured for use as fine aggregate supplement in the production of pre-mix concrete having characteristic strength up to and including Grade N25 concrete for use in non-structural concrete applications.

2.5 Guide Specifications for Crushed Cullet Sand(CCS)

2.5.1 Graded cullet sand, must be dimensionally stable with regard to variations in moisture content and sufficiently strong for the desired grade of concrete. It shall comply with grading limits specified by AS 2758.1 and have suitable particle shape and surface texture. Additionally, CCS must neither contain reactive contaminants nor adversely react with cement or reinforcing steel.

It is recommended that initial evaluation of crushed cullet sand(CCS) for pre-mix concrete production involve direct comparison of physical and mechanical properties plus durability characteristics of trial concrete mixes, using conventional natural fine sand as the reference material.

2.5.2 *Grading:* Crushed cullet should be processed to a fine aggregate size (less than 2.46 mm) and blended with conventional aggregates to conform to the grading requirements of AS 2758.1.

Plant grading of CCS depends primarily on crushing process adopted and careful setting of sieve sizes is required to achieve recommended nominal uniform grading, since material grading can significantly alter its engineering performance. Grading is often used as one of the key engineering requirements for acceptance in construction applications.

Only minor variation in sieve analysis of CCS can occur for material obtained from different sources. Thus, aggregate supplied as a mixture of different sizes should be uniformly blended.

2.5.3 *Bulk Density*: The bulk densities of glass and natural sand should be determined. Natural sand may tend to have a higher bulk density partly due to its inherent higher moisture content. The measured mean specific densities of clear, green and brown cullet were respectively 2.46, 2.49 and 2.48. This compares favourably with typical SG of natural sand of the order of 2.61.

2.5.4 *Foreign materials content:* Crushed glass often contains paper and plastic not normally found in natural aggregates with caps and labels as the most common contaminants. Compared to conventional aggregates, crushed glass may appear gritty with somewhat dirty surface, owing to dirt picked-up, scratches, and pitting during processing.

2.5.5 *Durability:* Glass is a brittle material and coarse particles greater than 2.46mm in size can be expected to break down during handling. Consequently, it is preferable to process (crush and screen) waste glass into a fine aggregate size, which is minus 2.46 mm, before it is used in concrete mixes.

2.5.6 *Absorption and moisture content:* Unlike natural sand, both water absorption capacity and moisture content of glass sand is relatively low. Insensitivity to moisture content would indicate that glass can be stored under varying moisture conditions compared to virgin aggregates. Therefore, the compacted density of glass aggregate is typically less sensitive to moisture content. In particular, since there is no need to compensate directly for aggregate water absorption in concrete mixes, only for moisture retained during stockpiling.

2.5.7 *Contaminants:* When used as aggregate in concrete, cullet should be cleaned of all organic residue, particularly sugar. When mixed in concrete, sugar causes an increase in setting time, and a decrease in the ultimate strength of the concrete.

Contaminants of organic origin with the potential to alter concrete properties include adhesive plastic and paper labels, and aluminium caps. Also, residual sugars can influence setting behaviour of concrete and, possibly, compressive strength. Soil and clay minerals can be deleterious whilst adhesives, for instance, may entrain air in the concrete. However, overall levels of such foreign materials in cullet were relatively low, and comprised mainly of plastic, ceramic and metal pieces.

2.5.8 *Alkali-silica reaction(ASR):* Certain types of aggregates and reactive quartz including plate glass can be susceptible to alkali silica reactivity leading to potentially dangerous expansive reactions under wet conditions. Thus where ever possible, the reactivity of CCS should be determined under conventional accelerated test conditions to establish their susceptibility to ASR

Inclusion of fly ash in the binder is recommended together with the adoption of a suitable concrete mix design to mitigate against potential ASR. However, more research is required to determine factors, if any, that govern CCS reactivity as well as novel remedial measures to combat potential ASR.

2.6 Cement and Admixtures

Chemical admixtures, cement and flyash or any other cementitious material should conform to existing Australian Standards.

3 Guide to the Specification of Recycled Cullet Concrete (RCC)

3.1 Recycled cullet concrete(RCC) shall contain uniformly graded crushed cullet to a maximum of 20% replacement of natural sand of 2.46mm minus maximum particle size. Specifications for, natural coarse aggregate, Portland cement or equivalent hydraulic binder or blended cement as specified by AS 3972 remain the same as for conventional concrete production. Admixtures shall comply with AS 1478 and their use shall be in accordance with AS 1479. The maximum aggregate grading and size requirement for concrete mix design remains unchanged for RCC as with conventional concretes.

3.2 Given appropriate aggregate properties and grading, CCS can partially replace the natural sand fraction to a recommended maximum of 20% for the production of plain and reinforced concrete for non-structural applications.

3.3 To effectively control concrete mix proportion, yield and workability, the particle density of CCS, water absorption and moisture content should be closely monitored during the course of aggregate production and storage.

3.4 Trial mixes are recommended to determine free water required to achieve specified slump. The free water to cement ratio for the specified strength and the ratio between fine and coarse aggregate necessary for optimum economy and cohesion of the fresh mix can also be determined as part of the trial mixing procedure.

3.5 The water requirement for satisfactory RCC workability should be determined at the trial mixing stage. In general, the basic principle of water:cement ratio applies to RCC without modification of concrete mix design. Thus, the free water:cement ratio required to achieve desired compressive strength remains the same for RCC as for conventional concrete and should always be the lowest value required for specified consistency and compressive strength.

3.6 In extreme situations, marginal loss of concrete slump due to an increase in fines content arising from excessive concrete mixing may be expected. For a given level of workability, increased CCS irregularity and roughness can also increase the mixing water requirement of the concrete.

3.7 In relation to mix proportioning, batching, placing and finishing, RCC is as easy to batch, mix, transport, place and finish as conventional concrete. Placing and finishing of RCC can be successfully achieved using standard equipment.

3.8 The cement requirement of uniform quality RCC appears similar to conventional concrete for equivalent strength and slump. The optimal ratio of coarse to fine aggregates for desired cohesiveness of fresh concrete remains approximately the same for RCC as conventional concrete. However, the cohesiveness of RCC may tend to improve with increased fine sand content for some CCS batches.

3.9 *Abrasion resistance:* The abrasion resistance of concrete is highly dependent on the quality of aggregate and the cement paste at both surface and near surface of concrete members. Aggregate wear is, in turn, controlled by its relative hardness.

For surfaces subjected to minimal wear exposure conditions with little exposure of coarse aggregates, surface toughness is mainly dependent on the properties of strong fine aggregates and good quality cement paste to provide required surface toughness. In all other applications, exposure of coarse aggregate may be acceptable so long as the rate of aggregate wear is satisfactory.

3.10 *Mechanical properties and Durability of RCC:* The elastic properties of RCC such as drying shrinkage are similar to conventional concrete. Fine aggregate has a marginal effect on the drying shrinkage of concrete since coarse aggregate remains the primary source of restraint to the paste fraction.

In most applications the most important property of concrete is its durability. The durability of concrete is indirectly related to the ease of permeability and transport of gases or liquids through the concrete matrix. Hence, permeability measurements are often indicative of the susceptibility to certain deterioration mechanisms. Practically all aspects of concrete durability are influenced by aggregate properties. Available data on RCC permeability is, however, scanty compared to corresponding data on conventional concretes of equivalent strength and binder type.

Very limited data is currently available on CCS durability in respect of resistance to sulphate attack, protection against steel reinforcement corrosion and sulphate soundness. Therefore, the exact tolerance limits and roles of chloride, sulphate and the effects of chemical contaminants in CCS are not certain. However some data exists for aggregate potential for expansive alkali-silica reactivity.

4.0 Background and Commentary on Model Specification

4.1 Glass cullet aggregate

In general, crushed cullet aggregate is durable, strong, and easy to handle and compact. The material can therefore be used in various construction applications including general backfill, roadways, utility backfill, drainage media, and miscellaneous uses such as landfill cover and underground storage tank backfill. For each application, specifications based on material performance are however required.

A range of laboratory tests as per AS 1141 and AS 2758(Aggregates and rock for Engineering Purposes) have been conducted on batch samples, including material grading, particle shape, texture, glass type and composition characteristics.

Glass collected from MRF facilities can be expected to exhibit a specific gravity of approximately 2.5. The degree of variability in this value depends on the degree of sample contamination.

4.2 Feedstock preparation

Material Storage and Handling

The same general methods and equipment used to handle conventional aggregates are applicable for waste glass. When combined with natural aggregates, crushed glass should be uniformly mixed.

Quality Control: The same field test procedures used for conventional aggregate are recommended for concrete applications when using waste glass. Standard laboratory and field test methods for compacted density apply.

Hazardous or Toxic materials: There should be no hazardous or toxic materials in recycled glass supplies. Cullet suppliers should ensure that such materials are kept out of the system.

Performance: Regular performance monitoring programs should be undertaken to better document the performance of granular glass material in actual applications.

4.3 Cullet crushing

Crushed glass(cullet) particles are generally angular in shape and can contain some flat and elongated particles. The degree of angularity and the quantity of flat and elongated particles depend on the degree of processing (i.e., crushing). Smaller particles, resulting from extra crushing, will exhibit somewhat less angularity and reduced quantities of flat and elongated particles. Proper crushing can virtually eliminate sharp edges and the corresponding safety hazards associated with manual handling of the product, as demonstrated in particle sizes lower than 2.46mm reported in this document. Table 1 lists some general material and handling properties.

When used in construction applications, glass must be crushed and screened to produce an appropriate design grading conforming to AS 2758.1.

Table1: General cullet material and handling properties

Materials constituents	Recycled glass may contain trace contaminants, such as non-recyclable glass (window glass, Pyrex, and drinking glasses), ceramics, plastic and metal bottle caps, lids, bottleneck rings, stones, and dirt.
General handling health and safety check	Precautions must be taken when handling glass. Safety gear such as heavy gloves, long sleeves, boots, and eye protection should be worn to protect handlers from broken and flying glass shards. General Consultation with safety office on procedures for handling glass.

Glass crushing equipment normally used to produce a cullet is similar to rock crushing equipment (e.g., hammermills, rotating breaker bars, rotating drum and breaker plate, impact crushers). Because MRF glass crushing equipment has been primarily designed to reduce the size or density of the cullet for transportation purposes and for use as a glass production feedstock material, the crushing equipment used in MRF's is typically smaller and uses less energy than conventional aggregate or rock crushing equipment.

Properly crushed and screened cullet can be free of sharp edges and glass slivers that meet general material requirements of fine aggregates.

Magnetic separation and air classification may also be required to remove any residual ferrous materials or paper still mixed in with the cullet.

4.4 Cullet feedstock

Waste glass should be free of ferrous and nonferrous metal, and the level of inorganic and organic debris should be reduced as much as practical. It has been recommended that levels of debris in the waste glass should be limited to 2% by mass. The standard test method often involves a visual test in which small samples are placed on a grid and extraneous debris counted and measured by weight.

Uncontaminated or clean glass itself exhibits consistent properties; however, the properties of waste glass from MRF's can be much more variable due to the presence of non-glass debris present in the waste stream.

4.5 Physical properties of cullet

Well-processed cullet/sand blend for concreting normally yield consistent physical properties.

Visual examination of the particles revealed a somewhat irregular, angular and rough textured morphology. These characteristics would normally necessitate the use of marginally higher water content to achieve desired lubrication for a workable concrete mix.

Selection of 2.46mm-cullet particle size was based on OHS and the ease with which material handling and concrete workability, placement and finishability can be achieved. When used in light traffic applications, concrete made with cullet must be user-safe against abrasion and wear.

Overall, the particle size and shape uniformity of the crushed glass sand is comparable to that of the natural sand used as reference material. The finely rushed glass contains no shards, since crushing produces more rounded and less sharp material. As a result, crushed glass aggregate appears to be no more dangerous than crushed rock aggregate.

Very fine sand or very coarse sand can both have undesirable effects on concrete finishing quality. The angular cullet particles may have an interlocking effect and less freedom of movement in the concrete mixture compared to rounded river sand, which gives greater workability. In general, cullet sand shows nearly similar characteristics as crushed sand with sharply angular shapes and rough surfaces.

Other essential material properties for cullet use as fine sand replacement in concrete include fineness modulus, deleterious particles content, particle shape, absorption, and specific gravity. Consideration must also be given to material attrition, which indicates level of grinding during mixing.

Typical maximum dry density of cullet is of the order of 1800 to 1900 kg/m^3. It has a unit weight of approximately 1120 kg/m^3, which is lower than that of conventional aggregate. The density of crushed glass will vary with the size and grading of the glass as well as the degree of contamination (including extraneous debris, such as paper, plastic caps, and soil), which is also somewhat lower than that of conventional virgin material. Crushed glass exhibits a relatively flat moisture-density curve, which indicates that the compacted density is insensitive to moisture content.

4.6 Typical Contaminants in Recycled Glass

Sugar

When mixed in concrete, sugar can cause an unpredictable increase in setting time and a decrease in the ultimate strength.

Visual inspection of otherwise clean glass cullet may not reveal the presence of sugar residue from previous food contents. Therefore, all cullet should be washed prior to its use as aggregate in concrete, if possible, a high temperature wash should be used to expedite the removal of sugar from the cullet. The glass can then be air-dried to minimize the addition of any uncalculated moisture to the concrete mix.

Ceramics
Ceramic contamination is a broad category including dishware, porcelain caps, pottery, heat resistant cookware (eg pyrex), mirror glass, laboratory glass, light bulbs, crystal and window glass. Ceramics can be removed manually or with automated systems.

Metal
Metal contaminants are generally in the form of container lids or seals. Typical ferrous metals include iron and steel, which are magnetic, and can be removed through magnetic separation techniques. Non-ferrous metal contamination includes brass, aluminum, lead, and stainless steel.

Organics
Organic contamination includes paper and plastic labels, plastic caps, cork, paper bags, wood debris, plants, food residue (e.g., sugar), and any other combustible or degradable material. Washing or passing the cullet through a screening device can remove organic material. Both metal and organic contaminants can be removed with a properly sized screen as these are less friable than glass and do not fracture as easily in glass crushers.

4.7 Durability

The additional processing (crushing) of the waste glass to produce material within the minus 2.46mm range eliminates the larger, less durable glass fraction. . It further entails safety considerations regarding exposure of the public. Crushed glass in this size range will perform as a highly stable (angular) fine aggregate material and exhibits consistent properties

The durability of cullet glass concrete exposed to wet environments, extended exposure to humid atmosphere, or in continuous contact with moist soil is yet to be determined.

4.8 Chemical composition and glass types

More than 95% of all manufactured glass is made from sodium oxide, calcium oxide, and silicon dioxide, commonly referred to as a soda-lime-silica composition.

A typical chemical composition of clear, amber and green cullet investigated is shown in Table 2. Given the differences in chemistry of different glass types, as shown in Table 2, there may also exist some variation in their reactivities in the cement matrix.

Table 2: Typical chemical composition of glass

Oxide Type	Flint glass	Green glass	Amber glass
SiO_2	72.4	72.38	72.21
Na_2O	13.64	13.52	13.75
K_2O	0.35	0.27	0.2
MgO	0.32	0.54	0.46
CaO	11.5	11.26	11.57
BaO	0.02	0.01	0.02
Al_2O_3	1.44	1.49	1.37
TiO_2	0.035	0.039	0.041
Fe_2O_3	0.067	0.294	0.255
Cr_2O_3	0.002	0.129	0.026
SO_3	0.207	0.069	0.099

Figure 1 shows a picture of minus 2.46mm sieve size fine clear glass used in the investigation. Overall, the particle size and shape uniformity of the crushed glass sand is comparable to that of the natural sand used as reference material. As observed in Fig 1, the finely crushed glass contains no shards, since crushing produces more rounded and less sharp material. As a result, crushed glass aggregate appears to be no more dangerous than crushed rock.

Fig 1: Photograph of crushed white glass cullet.

4.9 Water Absorption

Higher absorption rates pose potential problems for concrete production given that water demand and workability of the concrete can be severely altered. The characteristics of glass cullet aggregates normally offsets inadequate concrete workability specifically due to possible variations in aggregate absorption rates. The low absorption rate of cullet sand does not however alter concrete properties. Table 3 summarises properties of crushed cullet sand.

Table 3: Properties of Crushed Cullet Sand(CCS)

Material Property	Crushed cullet (-2.46mm)	Test method*
Specific gravity	2.4 to 2.5	AS 1141. 4
Water Absorption (max)	<1%	AS 1141. 6
Total Impurity level(max)	2%	-
LOI(max)	5%	-
Lost substances in washing (max)	1%	-
Particle size distribution by dry sieving	-	AS 1141.11

*AS 1141.3.1 -1996: Sampling of aggregates; AS 1141.4 -1996: Bulk density of aggregates; AS 1141.6.2 -1996: Particle density and water absorption of aggregates.

4.10 Chemical Contaminants

The extent to which chemical contaminants are likely to adversely affect concrete properties may be assessed through suitable leaching or related test method. Where environmental concerns are raised over stockpiles, leachate concentrations should be analysed to ensure compliance with existing regulatory limits.

Sufficient care must be taken to avoid inclusion of clay lumps and other degradable organic contaminants by adhering to standard practices of cleanliness such as aggregate washing or equivalent procedures where deemed necessary.

The key contaminants of concern, which could have potential adverse effect on concrete properties, include organic matter and other “soft” components such as wood and, plastics, which can influence concrete setting and hardening behaviour.

Cullet Handling

4.11 Processing and Mixing.

Specifications may require that the processed glass be blended with natural aggregate to a specific percentage. Because blending adds extra costs and can be difficult in the field, the specifying engineer should consider the need for uniform blending. In all applications, it is important to attain uniform blending. The blending process should prevent segregation of particles. Blending could occur during mixing in the truck.

Cullet sand should be specified, measured, batched and mixed in conformance with specifications for normal premix concrete.

Grading: The specifying engineer should begin with the same grading as is required for natural sand in the application, then consider whether the function of the glass is to replace the natural aggregate with the same grading or complement it with a grading that improves concrete properties.

Crushed glass collected from MRF's can be expected to exhibit a relatively wide variation in sizes. Differences in grading are dependent, in great part, on the type of glass crushing equipment used. In general, however, crushed glass can be expected to be a well-graded material, and properly sized cullet or cullet-aggregate mixtures can yield engineering properties that compare very well with natural sand aggregate.

4.12 Safety

While glass is produced with silica sand the manufacturing process converts the crystalline structure to an amorphous state. Tests have shown that recycled container glass contains less than 1% crystalline silica content.

Container glass is made from over 70% silica. The term silica refers to the naturally occurring mineral silicon dioxide (SiO_2). Crystalline forms of silica, also known as "free" silica, can contribute to certain lung diseases. An understanding of the difference between glass dusts and silica dusts in the crystalline form, and what the permissible exposure limits are, it is necessary to ensure worker safety and to avoid liability in recycled glass processing.

4.13 Glass Aggregate Dust

The production of glass aggregate requires crushing, which inevitably creates fine particles of glass. When the aggregate is moved around construction sites, these particles can become airborne as dust, which may present a nuisance to workers in the vicinity. It is therefore suggested that general procedures for worker protection and dust control should be implemented on the construction site.

Cullet users should carefully evaluate the potential effects of each type of contaminant on the intended application, and develop specifications for contaminant tolerance and removal. Awareness of typical recycled glass contaminants will help end-users develop application-specific standards for cullet grades.

In considering glass dusts, it is important to evaluate both the chemical composition of glass and its physical state. Bottle glass is a silicate containing various other ingredients, which have been melted and upon cooling, form an amorphous, or non-crystalline structure. The majority of the raw material silica occurs as quartz, a crystalline form of SiO_2. Other crystalline forms of silica include tridymite and cristobalite. While SiO_2 is a primary ingredient in the manufacturing of bottle glass, when glass is formed, the crystalline structure is changed to an amorphous structure and the SiO_2 is no longer considered crystalline.

The development of disease depends on several factors, including percentage of free silica in the dust.

Glass composition is fairly consistent, however periodic testing of both raw materials and dust levels in the workplace is recommended

Studies conducted on glass dust to determine the presence of crystalline silica shows that cullet aggregate typically contains less than one percent crystalline silica by weight, and may therefore not considered hazardous.

Glass cullet dust can be a skin and eye irritant. Because cullet particles are abrasive due to their high angularity in particle shape, they appear to be more irritating than dust from natural aggregate or soil. However, experience gained on construction sites has indicated that cullet dust, and the irritations associated with cullet dust, can be easily suppressed using simple measures.

Large stockpiles of dry material with more than 5% to 10% fines can generate a dust cloud, which can be transported by wind a great distance.

Suitable safety gear should be used when working with cullet aggregate. It is recommended that personnel be made aware that direct skin contact with the glass cullet should be avoided. Also, heavy gloves, long-sleeved shirts, heavy boots, hard hats, and ear and eye protection are required when working with finely crushed cullet aggregate.

Understanding the hazards of cullet aggregate dust, and the associated preventative measures will help create a safe worksite environment and lessen the environmental impact on site vicinity.

Construction personnel should be made aware of the potential inhalation hazard and skin and eye irritation. All personnel should have knowledge of preventive measures, but the responsibility of such measures should be clearly assigned.

Concrete trials using cullet sand

4.14 Preliminary Laboratory trials

Waste glass was crushed and screened to produce a material that satisfied the grading requirements of concrete sand in accordance with AS 2758. Glass of 2.46mm-minus size cullet was selected partially because this has a grain size close to that of a fine to coarse sand.

Concrete Mix Design:
Conventional Australian Standards concrete mix design procedures can be employed for concrete containing cullet as sand replacement.

Crushed waste glass (cullet) used in granular base applications should be limited to the replacement of fine aggregate sizes. Fine crushed glass contains durable sand-like particles.

Several preliminary trial mixes were proportioned to evaluate water requirements for a nominal 25MPa concrete. The mixes were proportioned to have a nominal binder content of 250kg/m^3 and contained varying amounts of cullet replacement for natural sand.

Concrete Density:

The mass per unit volume, ie density, of freshly mixed concrete was determined in accordance to AS 1012.5. Fig 2 shows the day concrete densities for varying clear glass cullet sand loadings. There is only a marginal reduction in concrete density at 30% cullet replacement for fine sand while a reduction of about 15% is observed at 100% cullet loading.

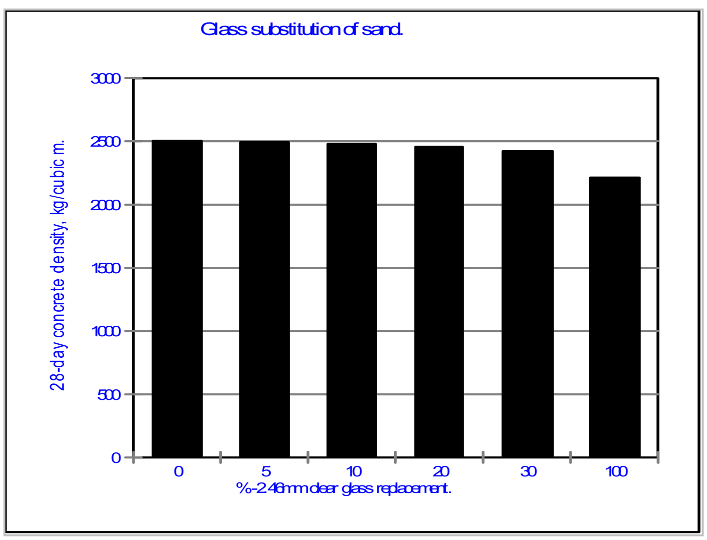

Fig 2: 28-day concrete densities at varying glass replacement levels.

Trial mixes:
Several preliminary trial mixes were proportioned to evaluate water requirements for a nominal 25MPa concrete. The unit water content of the concrete was corrected for free moisture in the aggregates. The mixes were proportioned to have a nominal binder content of 250 kg/m^3 and contained varying amounts of cullet replacement for natural sand.

These preliminary test disclose that the inclusion of 100% cullet sand generally produced a less cohesive mix, i.e., stiff concrete compared to the reference natural sand mixture. Consequently, concrete trial mixes were redesigned to improve their cohesiveness and workability.

Properties:
Based on visual evaluation of bleeding characteristics, the glass concretes also showed dissimilarities in behaviour to the control basalt concrete, in respect of concrete bleeding and cohesiveness, as indicated in Table 4. Bleeding refers to the phenomenon whereby some water rises to the surface of freshly placed concrete. There was however some discernible relationship between mix ingredients and flow characteristics in respect of overall harshness of the glass concrete mixes.

Table 4: Summary of concrete wet properties

Concrete Mix Code	**C1810A**	**C2809B**	**C3009A**	**C3009B**	**C3009C**	**C0610A**
Slump(mm)	60	75	90	100	95	65
Flow (sec)	<3	<2	<2	<3	<5	<2
Wet density (kg/m^3)	2216	2429	2443	2475	2489	2496
Bleeding	yes	yes	yes	yes	yes	v little
Cohesive	yes	no	no	no	no	yes

4.15 Compressive Strength

Compressive strengths determined on concrete cubes continuously stored under moist conditions for up to 91days. As shown by the mean compressive strength results plotted in Fig. 3, there is progressive reduction in strength with increasing glass content. A corresponding 5% reduction in strength at 5% glass substitution is obtained compared to a 27% reduction at 30% glass substitution. The relative difference in strength development between 10% and 20% cullet replacement is of the order of 7%.

The rates of strength development are however identical for all mixes. This latter trend suggests that the observed strength reduction perhaps has a physical rather than a chemical effect on concrete properties.

This progression generally follows a near-linear correlation between 5% and 30% cullet replacement levels. Minimal reduction in strength prevails at 5% replacement compared to nearly 50% reduction at 100% cullet replacement level.

A maximum cullet content of 20% sand replacement level in premix concrete mix applications was adopted based on results of preliminary concrete trials.

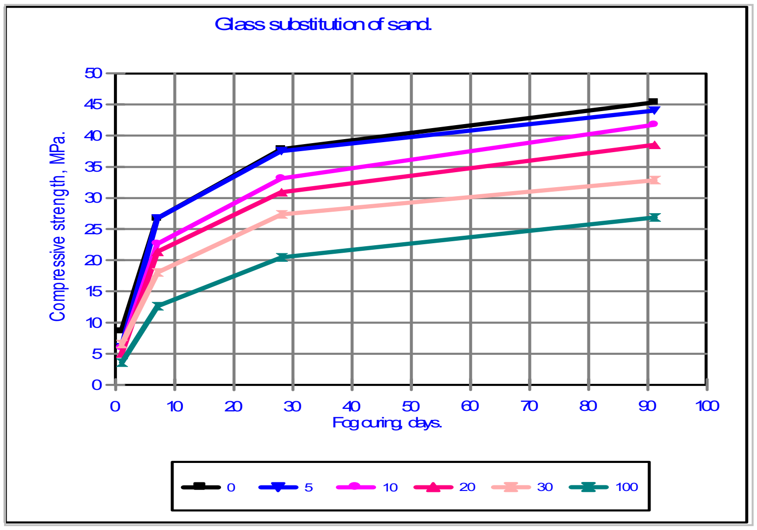

Fig 3: Compressive strength development

The progressively linear decrease in compressive strength of concrete with increase in glass replacement levels for sand is more evident with the 28day compressive strength plots shown in Fig 4.

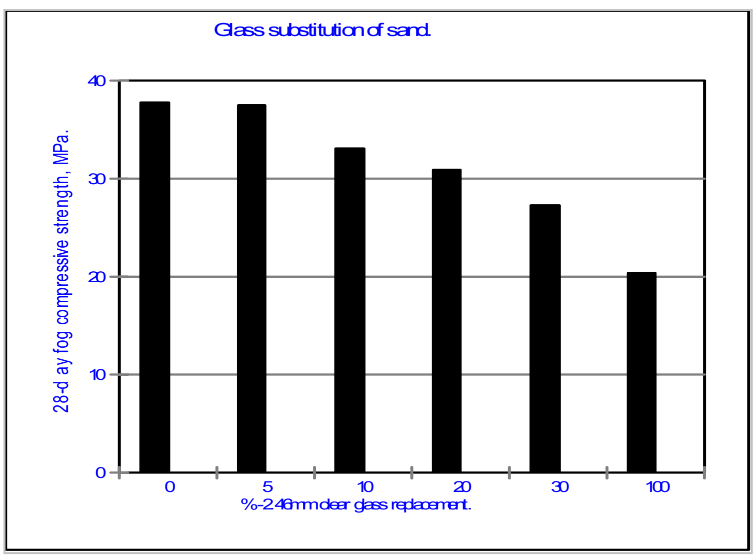

Fig 4: 28-day compressive strength at varying cullet content

A plot of the strength development for individual colours of cullet at 30% replacement level compared to the reference mix is shown in Fig 5. Fig 5 shows a strong dependency of compressive strength on colour of cullet. The basis of this correlation is not immediately clear even when chemical composition of the glass is considered.

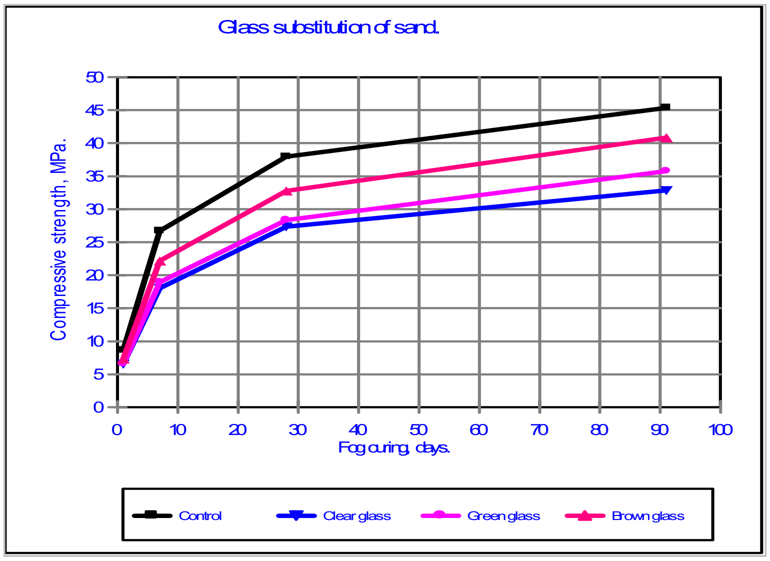

Fig 5. 91-day compressive strength of concrete made with different colour cullet sand

4.16 Drying Shrinkage

The 56-day dry shrinkage values of concrete containing different levels of cullet sand are shown in Fig 6. The elastic properties of glass concrete such as drying shrinkage appears lower than the conventional reference concrete.

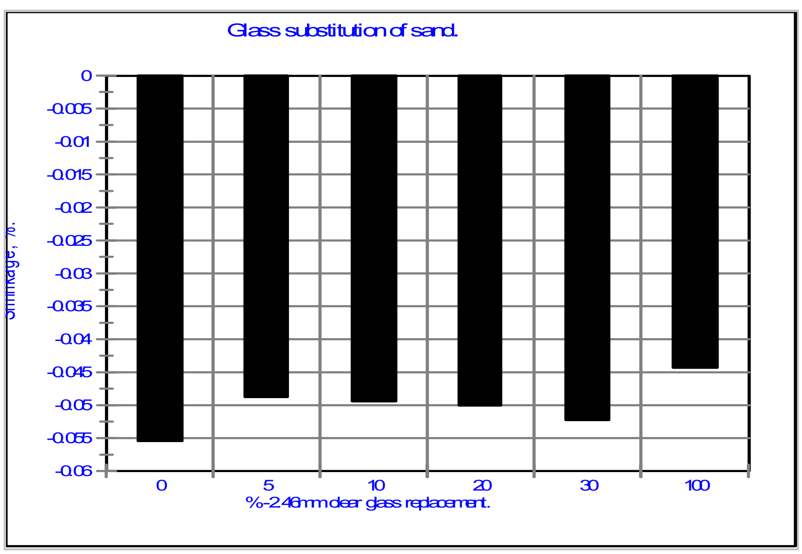

Fig. 6. The 56-day dry shrinkage values of concrete containing different levels of cullet sand

In general fine aggregates have a less dominant effect on the drying shrinkage of concrete, as they are not the primary source of restraint to the paste fraction. Similarly, absorbent fines can alter the drying shrinkage of concretes.

There is a significant influence on drying shrinkage with the inclusion of cullet as shown in Fig 6. The measured shrinkage values of nearly all concretes containing cullet were well within the 700-microstrain limit at 56 days. Indeed the shrinkage values of specimens containing glass were nearly 20% or more less than the reference sample.

There appears to be no direct correlation between cullet loading level and the extent of measured drying shrinkage.

4.17 Alkali Silica Reactivity(ASR)

Glass is generally considered an inert material; however, it is not chemically resistant to hydrofluoric acid and alkali. Expansive reactions between amorphous silica (glass) and alkalis (such as sodium and potassium found in high concentrations in high alkali Portland cement) could have deleterious effects if glass is used in Portland cement concrete structures.

An adverse result of using glass cullet in concrete is the alkali-silica reaction (ASR). Concrete producers have known ASR for many years because it can also occur when using vitreous (glassy) rock or slags with high amorphous silica content. The silica from the cullet or aggregate can combine with the alkalis in Portland cement to form a siliceous gel. This gel will then absorb water and expand, causing structural weaknesses in the concrete.

Reducing the reactants present in the concrete mix can minimize the alkali-silica reaction. Because the cement is the source of the alkalis (Na_2O + K_2O), low alkali Portland cement could be used. The American Society for Testing Materials defines low alkali cement as consisting of less than 0.60% by weight of alkalis. The amount of alkalis can also be reduced by replacing up to 25% of the ordinary Portland cement with a low alkali siliceous pozzolan, such as ASTM Class F fly ash.

The impact of ASR can also be alleviated by minimizing the amount of moisture in the concrete mix, which will decrease the expansion of any gel produced. However, using less water will also cause an increase in viscosity, thereby decreasing the “slump.” The resulting mixture may be difficult to pour. If a lower viscosity is needed, a High Range Water Reducing (HRWR) admixture can be added.

In addition, some research suggests that a higher proportion of green glass in the cullet source may also suppress the ASR. This may be due to the higher concentration of chromium oxide in green glass, although adding this chemical directly to the concrete mix does not appear to affect the reaction.

Different glass types or other particles susceptible to alkali silica reaction or alkali carbonate reaction have the potential to initiate and propagate deleterious reactions to varying extents in cementitious systems.

The silica from a reactive aggregate can combine with the alkalis in Portland cement to form a siliceous gel. This gel will then absorb water and expand, causing structural weaknesses in the concrete. Fig 7 shows an electron micrograph of an angular cullet particle in a mortar matrix of ASR test sample. Fig 8 shows possible relicts of gel formation.

For alkali silica reactions to occur in concrete, a critical quantity of reactive silica component in aggregates in addition to sufficient moisture(>75% rh) and sufficiently alkaline concrete pore fluid are essential. Specified limits of alkali content of cements and use of blended cements have the potential to mitigate deleterious alkali-aggregate reactions. As shown in the mean expansion plots of single-colour cullet concrete with and without fly ash of Fig 9, inclusion of fly ash in the binder can significantly offset potential ASR reactivity of glass at the size fraction investigated.

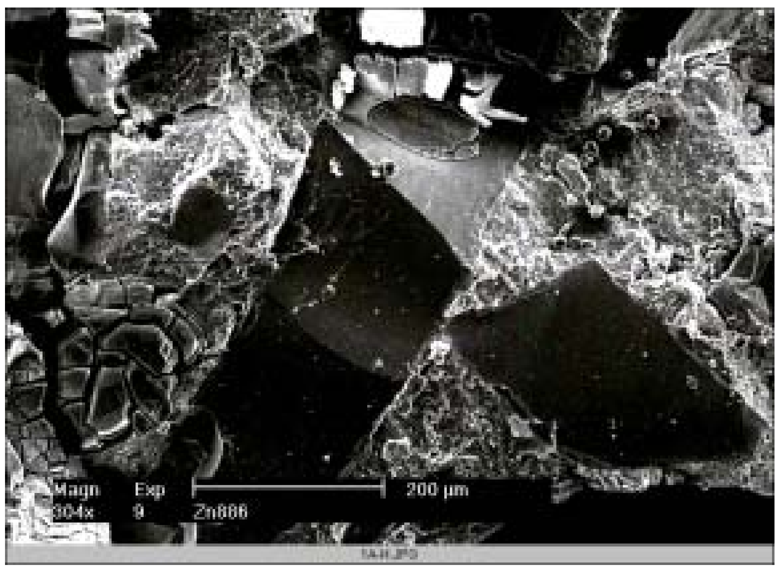

Fig 7. Electron Micrograph showing angular cullet particle in mortar matrix of ASR sample

Certain types of aggregates, reactive quartz and plate glass can be susceptible to alkali silica reactivity(ASR) leading to potentially dangerous expansive reactions under wet conditions. Thus where ever possible, the reactivity of glass should be determined under conventional accelerated test conditions to establish their susceptibility to ASR.

The investigation, at this stage, did not cover the effects of glass aggregate particle size, conventionally known as the ‘pessimum effect”. The pessimum effect relates to the size of aggregate at which maximum expansion occurs due to ASR reaction. This implies that ASR expansion increases with increasing fineness of aggregate particles up to a certain threshold, and then decreases afterwards. However, for practical purposes the reactivity of glass has to be suppressed which, in this project, is controlled with the use of binders incorporating fly ash.

Fig 8. Probable gel formation in ASR test sample

The use of blended cements is often recommended together with the adoption of a suitable concrete mix design to mitigate against potential ASR. However, more research is required to determine factors, if any, that govern cullet reactivity as well as novel remedial measures to combat potential ASR.

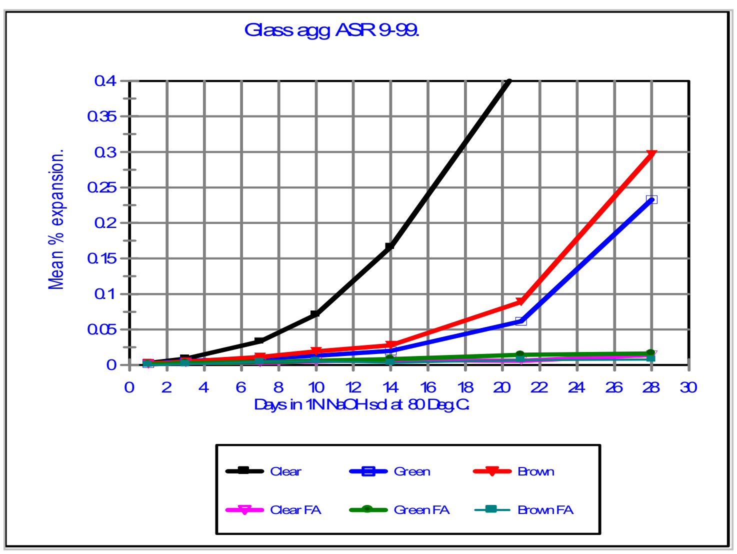

Fig 9. Mean expansion of cullet concrete with and without fly ash

The relation between different Fly ash levels in controlling ASR is depicted in Fig 10 which plots expansion rates for varying ash content in the binder. It is evident that 20% or greater Fly ash supplement of cement has a net effect of lowering potential ASR reactivity.

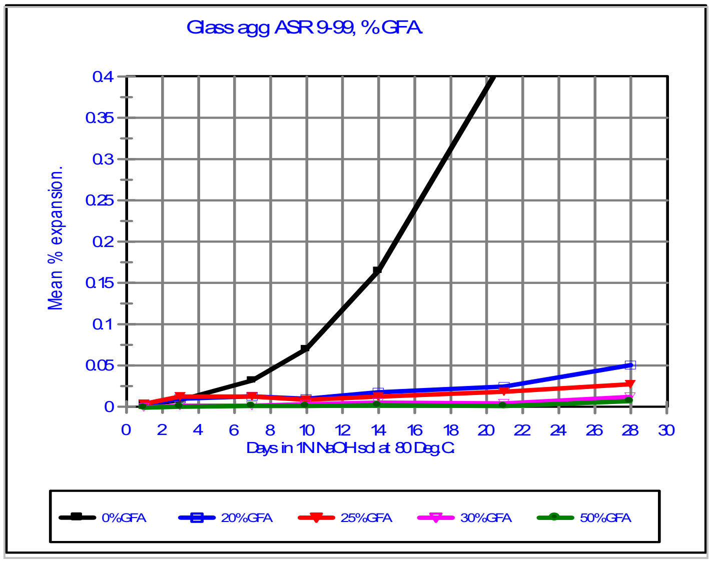

Fig 10: Effect of Fly ash additions on concrete expansion.

As shown in Fig 11 fly ash cement binder mixtures, have the potential to mitigate potential ASR in glass concrete mixtures containing up to 100% glass. (It is suspected that the sand used in the investigation reported in Fig 11 might be moderately reactive)

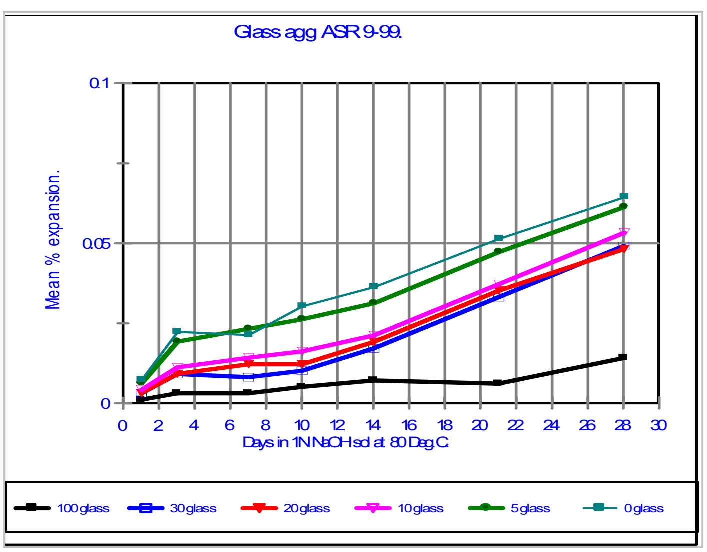

Fig 11. Mean expansion rates for concretes made with varying glass contents.

The use of different Portland cement types, particularly low alkali cement, to help control this reaction is also well known.

4.18 Comments on ASR

When glass cullet is arbitrarily combined with Type GP (ordinary Portland cement), chemical reactions can occur which may reduce the strength of the concrete. Sources deleterious reactions may include sugar contamination and an alkali-silica reaction. The silica from the cullet or aggregate can combine with the alkalis in Portland Cement to form a siliceous gel. When incorporated in concrete, ASR-susceptible aggregates may cause expansion and cracking.

Possible adverse effects of using glass cullet in concrete due to sugar residue contamination and alkali-silica reaction (ASR) can be minimised using a combination of the following:

- Use of Type GB (blended cements): Minimum: 25% Fly ash
- Washed glass aggregate
- Use of low alkali cement
- Reduction of moisture content
- Increasing surface area to volume ratio of glass aggregate

5 PRACTICAL CONSTRUCTION PROCEDURES and C0MMENTARY ON MODEL SPECIFICATION

The quality of concrete construction is largely determined by the workmanship. Proper performance of a structure therefore largely depends on construction that correctly meets code requirements, these being relevant existing Australian Standards in the absence of alternative codes for marginal materials use in construction.

In respect of concreting practice, conventional methodologies for material storage and batching of virgin materials as well as procedures for proportioning, mixing, handling, transporting and placing of normal premix concrete apply to glass cullet concrete. Cullet sand should conform to the general requirements of fine sand aggregate requirements of AS 1141.

Generally, compliance requirements and inspection requirements will include:

- Quality and proportioning of concrete materials and strength of concrete
- Construction and removal of forms
- Mixing, placing and curing of concrete
- General progress of work

Typically, glass cullet sand must be viewed as a nonconforming material requiring approval, based on demonstration of satisfactory and acceptable performance. Such non-complying materials are traditionally required to have a history of satisfactory performance in actual service, and a demonstration that they can be used to produce concrete of adequate strength and durability. This information is only now beginning to emerge for glass sand blends.

Data from field trials included in this document was generated from direct head-to-head technical comparison of similarly specified commercial premix concrete made with and without coarse recycled concrete aggregate. This procedure was designed to enable comparative performance assessment of both field and laboratory samples including regular field inspections. Test specimens for each concrete batch were 100mm diameter cylinders for compressive strength tests and 75x75x300mm prisms for shrinkage measurements. These measurements were considered critical given that the engineering properties of concrete such as compressive strength and drying shrinkage and elastic modulus are influenced to different extents by the proportion and type of coarse aggregates used in the concrete mix.

Cast concrete test samples were normally demoulded after 24hours and subjected to curing regimes dictated by the type of test. Field measurement of concrete drying shrinkage were performed in-situ on experimental slabs cast adjacent to each constructed facility. Cored sections of field test pads provided samples for compression testing at stipulated times. Concrete compression tests were carried out under AS 1012.9, shrinkage tests according to AS 1012.13. Slump measurement and other fresh properties of the concrete mixes were similarly evaluated based on standard test methods.

Table 5 shows mix proportions and measured wet concrete properties of reference natural sand and cullet glass concrete investigated during the field trials.

Table 5: Concrete mix proportions and measured properties

Mix proportion	Natural sand Concrete	Glass cullet Concrete
Type GP Cement(kg)	250	250
Fly Ash(kg)	76	76
Admixture GWR(litre)	1.28	1.28
Water/Binder*	0.43	0.43
Basalt-14/19mm (kg)	990	990
Fine sand(kg)	880	790
Glass cullet(kg)	-	220

*Excluding aggregate moisture content

	Slump	Air Content	Ambient Temperature
Natural sand concrete	75mm	2.5%	18ºC
Glass cullet concrete	90mm	3.0%	18ºC

5.1 Glass cullet concrete production

The same methods and equipment can be used to mix, place, and compact cullet concrete mixes and conventional concrete mixes. For normal operation, the concrete is usually discharged within one hour after mixing has started.

The water requirement for satisfactory concrete workability should be determined at the trial mixing stage. In general, the basic principle of water:cement ratio applies without modification of concrete mix design. Thus, the free water:cement ratio required to achieve desired compressive strength remains the same for cullet concrete as conventional concrete and should always be the lowest value required for specified consistency and compressive strength. Trial mixes should be made in order to adjust free water required to offset possible variations in water absorption of different aggregate batches.

Tests should be conducted to relevant Australian Standards, e.g. concrete compression strength, to AS 1012.9 and the methods for the preparation and determination of drying shrinkage/expansion of concrete under laboratory exposure conditions in accordance with AS 1012.13.

Concrete shall be transported to the site and delivered in agitator trucks constructed, maintained and operated in compliance with the requirements of AS 1379.

6 Field trial and commentary on concrete production, placement and curing

Materials specification
Material storage, grading, density, contaminants, etc

AS 1141
AS 2758.1

All concreting materials and specified test procedures should conform to relevant Australian Standards. Materials should be stored in such a manner as to prevent deterioration or contamination of foreign material.

Glass cullet aggregate grading should conform to the general specification for fine sand and should match the broad specifications outlined in this document

Alkali silica reactivity
AS 1148.38
AS 1148.39

All necessary precautions should be taken to ensure that the durability of glass cullet concrete is not compromised especially in relation to alkali-silica reactivity.

Concrete, slump, strength and durability requirements should be shown on contract documents.

Fresh Concrete Properties
Concrete manufacture, mix design and chemical admixtures
AS 1012
AS 1379
AS 1478
AS 3582.1 Fly Ash
AS 3582.2 Slag
AS 3972

The same equipment and procedures used for concrete containing conventional fine aggregate may be used to batch, mix, transport, place, and finish concrete containing cullet sand.

Concrete Density

The densities of the cullet concrete were generally within 10% of the reference natural sand concrete. Concrete placement, compaction and the setting behaviour of fresh cullet-concrete were found to be similar in most respects to the reference mix.

Workability

The workability of glass containing minus 2.46mm cullet as sand replacement was found to be generally good, although all glass concrete mixes were characterised by a somewhat stiff texture. The main factors affecting the slump and workability were the texture and shape of glass sand. The angular shape of glass sand however did not seem to alter the internal friction of concrete which normally requires more mortar to improve concrete workability.

Setting characteristics

The variation in setting characteristics with partial substitution of cullet for natural sand was practically identical with that of the control. As a whole, such similarity in fresh setting behaviour indicates that cullet will have no apparent adverse impact on fresh concrete setting characteristics.
Identical moist curing conditions were used for glass cullet concrete as for normal aggregate concrete in accordance with recommendations of AS 3600. Results obtained confirm that no additional curing may be necessary for glass concrete compared to conventional concrete mixtures.

Base coarse preparation

Normal base-course preparation for conventional concrete involving use of crushed rock or recycled concrete is required.

Fig 12. Basecourse preparation

Fig 13. Close-up of basecourse

Slump
As 1012.3

The slump, air content, and temperature of the plastic concrete monitored at the time of placement, in accordance with procedure of AS 1012.3, AS1012.9 etc

Fig 14 shows a photograph of slump test for glass cullet concrete. For equivalent mix design comparable slump values were obtained for cullet glass and reference concretes. On-site slump test may be requested as needed.

Fig 14. Photograph of slump test of glass cullet concrete

Concrete placement and compaction

The same quality-control procedures for conventional premix concrete pavement are required for concrete incorporating glass cullet sand.

AS 1379
AS 3600

Close attention must be paid to possible effects on concrete workability, ease of consolidation and susceptibility to segregation during concrete placement. The workability and methods of consolidation should be such that the concrete can be placed without voids or honeycombs.

Concrete should be compacted to ensure maximum density is obtained and that complete contact between concrete and all fixtures including reinforcing steel is achieved. Vibrate placed concrete for maximum consolidation of concrete.

Glass cullet concrete placing, compaction and setting behaviour of fresh cullet concrete was found to be similar in every respect to the reference basalt mix. Concrete workability and bleeding characteristics were also found to be comparable.

Fig 15. Placement of cullet concrete

Finishing

Field data suggest that cullet glass concrete may be finished to the equivalent standards for conventional concrete, including levelling, floating, trowelling, special finishes, using traditional finishing tools and equipment. General colour uniformity is achieved with glass cullet concrete and is non-staining.

The placement of glass cullet concrete was particularly facilitated by the fluid nature of the concrete. No apparent visible differences in concrete workability and finishability were observed. The rates of concrete setting also appeared to be similar.

Fig 16. Finishing of section of glass cullet concrete

Movement Joints

Fig 17. Finishing of cullet concrete

The Contractor shall construct movement joints as shown on the drawings and as provided by the relevant specifications.

Curing

Immediately after finishing operations have been completed the concrete should be cured in accordance with specification. The purpose of curing is to maintain moisture within the concrete while the cement hydrates. The surface of improperly cured concrete is often less durable than cured concrete.

Conventional curing practices, either moist curing or by use of curing compounds, may be readily applied to glass cullet concrete.

Instrumentation

Fig 18. Finished cullet concrete for curing

Field measurement of concrete drying shrinkage were performed in-situ on experimental slabs cast adjacent to each constructed facility. Cored sections of field test pads provided samples for compression testing at stipulated times.

Fig 19. Instrumentation of cullet concrete to monitor concrete dimensional stability.

FIELD DATA

Compressive strength

AS 1012
AS 1379

Concrete compression tests were carried out under AS 1012.9 and drying shrinkage tests in accordance with AS 1012.13.

Furthermore, the results of field trials disclose that there is no significant difference between the setting behaviour and rate of strength development of glass cullet and reference concretes.

The 91-day fog cylinder compressive strength of glass cullet and reference concretes was 40MPa and 41.6MPa respectively, representing less than 4% difference in strength, as shown in Fig. 20.

The corresponding in-situ compressive strengths observed for cylinders cured outdoors for both glass cullet and reference concretes at 91 days were generally similar to strengths achieved for the standard fog-cured samples as shown by the field test results of Fig 21.

The rates of strength development are comparable for all test times and the specified 28-day strength was achieved. A 32MPa grade concrete was specified for both mixes.

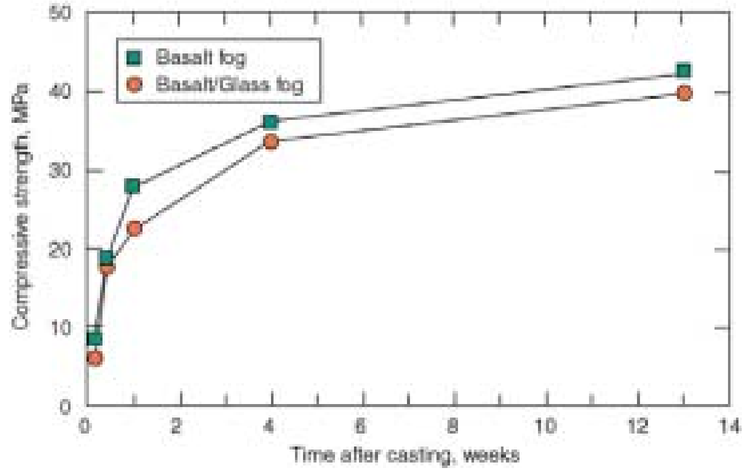

Fig 20. Compressive strength of fog-cured glass cullet and reference basalt concrete

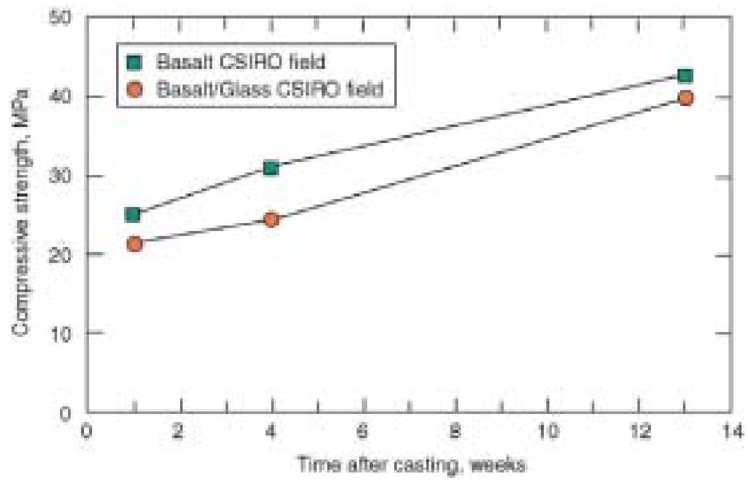

Fig 21. Compressive strength of CSIRO field cured glass cullet and reference basalt concrete

The compressive strengths of concrete cores, shown in Fig 22, was of the same order as for standard fog cured samples although the magnitude of overall strength levels were somewhat lower.

The core strengths are comparable to those observed under standard fog-cure conditions indicating that the ambient field curing conditions was fortuitously rather effective. As shown in Fig 22, the field strengths at 28days were lower than specified, particularly for the glass cullet samples. Equivalent strengths comparable to the standard fog cured samples are however obtained at 91days.

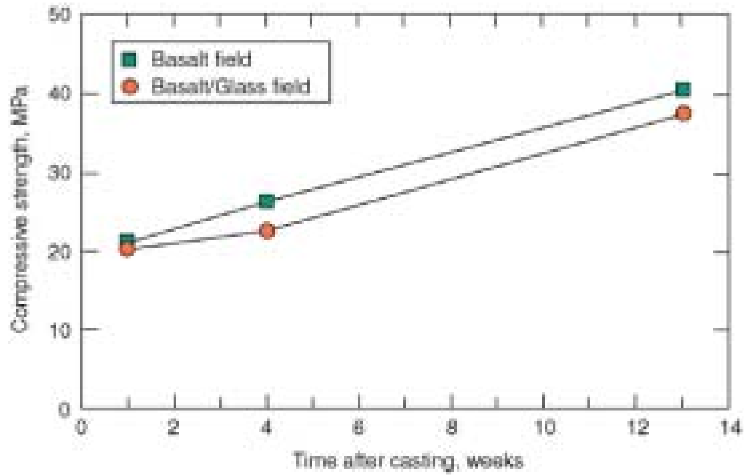

Fig 22. Compressive strength of cored field-cured concretes

A correction factor of 0.92 was applied to measurements obtained for cored samples as per BS 1881 Part 4 owing to reduced length/diameter(l/d) ratios obtained for the cored samples compared to standard l/d ratio of 2, for cylinders.

Dimensional stability.

Fig 23 shows the dimensional stability of glass cullet and reference concretes observed for continuously moist cured specimens up to 13weeks. Similar trends are evident. However, the shrinkage data of the glass cullet concrete after 1 day mould and 6 day fog curing followed by continuous drying at 23°C and 65% rh are generally similar to that of the equivalent reference concrete. The shrinkage of the reference concrete is only marginally higher and well within statistical experimental variation.

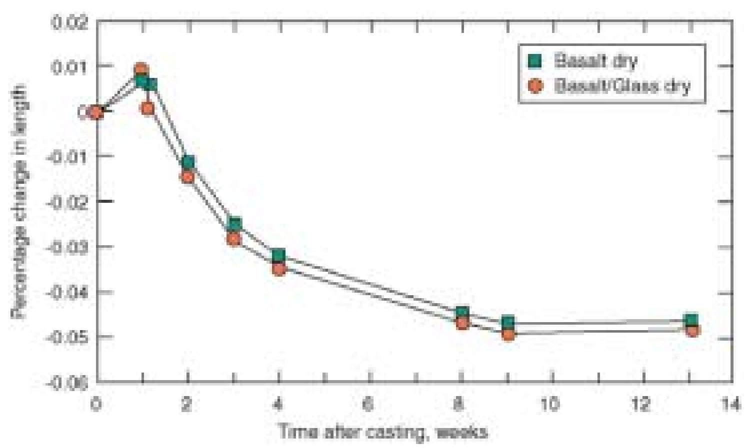

Fig 23. Standard shrinkage measurements

The rates of strength development are comparable for all test times and the specified 28-day strength was achieved. A 32MPa grade concrete was specified for both mixes.

In-situ field shrinkage data is plotted in Fig 24. Overall shrinkage values recorded for both glass cullet and the reference concretes are lower than values obtained for the corresponding standard exposure samples shown in Fig 23. The measured values are significantly lower than the typically specified values of 700microstrain at 56 days.

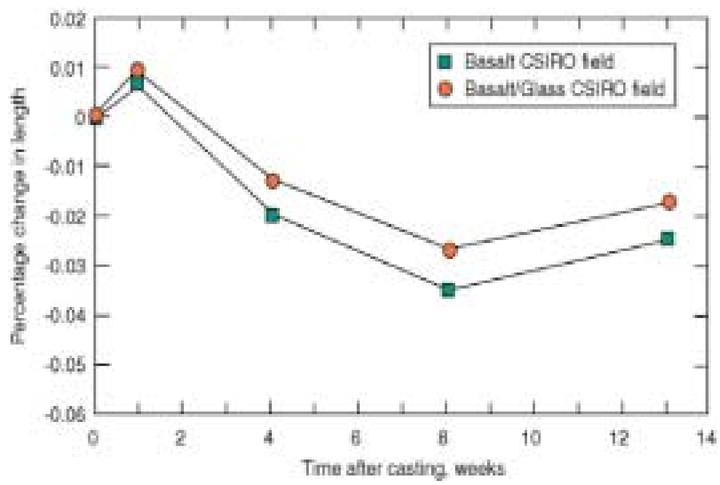

Fig 24. Field shrinkage measurements