NZTA M04 Notes: 2024

Notes to the Specification for Basecourse Aggregate

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NZ TRANSPORT AGENCY

Te Kāwanatanga o Aotearoa
New Zealand Government

1 Scope

NZTA M04 specifies the properties of basecourse aggregates for use in pavements. The term basecourse is defined as the uppermost pavement layer adjacent to the surfacing. Aggregate compliant with M04 specification is not suitable as the wearing course for an unsealed road.

Lower layers, where performance requirements allow a lesser quality material, should be referred to and specified as "sub-base".

The aggregate is specified in terms of physical properties, with the source rock used to produce the basecourse aggregate tested for minerals content, strength and durability and the finished product tested for fines quality, physical properties and resistance to deformation under traffic load.

2 Aggregate Classes

This specification describes four aggregate Classes to be selected on the basis of expected loading in the pavement. The Classes are defined in Table 1 below.

Table 1: Aggregate Classes

Aggregate Class	Duty	Loading (ESA)
Class 1	Very Heavy	Less than 10^7
Class 2	Heavy	Less than 5×10^6
Class 3	Medium	Less than 10^6
Class 4	Light	Less than 10^5

The aggregate Class, or quality, should be selected to match the expected duty in the pavement, i.e. higher Class aggregates are not intended for lighter duty applications unless there are good engineering or economic reasons to do so. The intention is to conserve the higher quality aggregates for pavements that require their superior properties.

Note: The loadings are aligned with the Waka Kotahi supplement to the Austroads pavement design guide. In the absence of contractual requirements assume the ESAs to be over a 25 year design life.

The traffic loading in Equivalent Standard Axles (ESA) should be regarded as a guide rather than setting absolute limits. Aggregate track record and engineering judgement should be used to select the most appropriate aggregate Class for a pavement. Specific regional criteria should also be considered, for instance frost heave in cold locations, when selecting an aggregate Class. Refer also to the Regional Basecouse Aggregates section of M04 specification.

3 Aggregate Quality

3.1 General

Basecourse aggregate quality is managed by specifying the quality of the source rock used to manufacture the aggregate, using tests that describe various properties of the produced aggregate and finally by bearing strength tests that model the aggregate performance in a pavement.

The criteria used to specify the aggregate properties are broadly the same for the four aggregate Classes, but the acceptance limits vary. The intent of the variances is to allow the use of aggregates in lower demand situations that previously could not be used. This is to make better use of aggregate resources in New Zealand, widening options for road controlling authorities and designers, preserving premium rock for high demand applications and reducing the need to transport aggregates from distant quarries.

3.2 Testing

Testing laboratories are required to be accredited to ISO/IEC NZS 17025. This means that the laboratory must be accredited by International Accreditation New Zealand (IANZ) or equivalent body (such as NATA for example). Where possible and practical the sampling and test results must carry the endorsement of the accreditation agency in the test report.

3.3 Source Properties

Aggregate strength is specified by the Crushing Resistance test. The variation between the Crushing Resistance carried out with oven-dry aggregate and with damp aggregate has been added to control any significant reduction in rock strength when wet.

Aggregate durability is controlled by the Weathering Quality Index test, as in previous iterations of M04. Additionally, the Ethylene Glycol Accelerated Weathering test has been added to M04 specification. This test amplifies the effect of deleterious minerals, such as smectite clays in the source rock and provides information on the long term durability of the aggregate. These clays can cause failure if present in granular pavements.

Where aggregate materials fail the Ethylene Glycol Accelerated Weathering test additional investigation of the mineralogy can be carried out by X-ray diffraction (XRD). This testing can identify if the non-compliance is a “false positive” or if deleterious minerals are present.

M04: 2024 also requires regular routine assessment of the source rock mineralogy using XRD.

3.4 Production Properties

The method for obtaining samples of finished aggregate from stockpiles has been explicitly restricted to machine (loader or excavator) methods in this update to M04 specification. This is to improve the representivity of samples as obtaining representative samples by hand sampling is very difficult.

The quality of the fines in the basecourse aggregate is assessed using several test methods, and these vary depending on the aggregate Class. The Plasticity Index criterion is preferred but this is mandatory for Classes 1 and 2 aggregates only. The fines quality for Classes 3 and 4 aggregate can be tested using either Plasticity Index, Clay Index or Sand Equivalent.

A Flakiness Index requirement has been added to this version of M04 specification for Classes 1 and 2 aggregates. The addition of this criterion recognises that the Particle Size Distribution test alone does not fully control aggregate packing, and that particle shape has a significant effect on workability and pavement density.

New acceptance limits for aggregate particle size distribution have been added for Classes 3 and 4 aggregates, while Class 1 and 2 retain the traditional limits.

3.5 Field Sampling

Where field sampling of the aggregate after spreading is required the method of NZS 4407 Test 2.4.7 (mat sampling) should be used.

3.6 Performance-Related Properties

Class 1 and Class 2 aggregates are required to have their deformation resistance assessed using the Repeated Load Triaxial (RLT) test. Classes 3 and 4 can similarly be tested but as a minimum they must be tested to determine their California Bearing Ratio (CBR).

Aggregate Maximum Dry Density (MDD) and Optimum Water Content (OWC) are determined using the New Zealand Vibrating Hammer compaction apparatus as has been normal practice.

3.7 Determination of Particle Size Distribution Compliance

3.7.1 General

It is recognised that demonstrating compliance with the particle size distribution requirements of M04 specification can be difficult, because randomness arising from stockpile construction techniques, sampling effects and testing uncertainties can make individual test results unreliable.

Consequently the intent of M04 is that compliance is determined for a stockpile in a quarry using the specified statistical tools.

Stockpiles of aggregate constructed in project sites fall outside of the control of the aggregate supplier. Therefore it is the responsibility of the project contractor to carry out enough testing, and use the statistical tools of M04, to provide assurance to the Principal that the site stockpile remains compliant; i.e. is not segregated or contaminated.

The update to M04 specification has taken steps to improve the reliability of quality assessment by:

(a) Requiring the use of process control tools and looking at sets of data
(b) For each test sieve calculating a rolling average of 5 test results to reduce random "noise" in the data
(c) Using a statistical parameter, the "Characteristic Value" to determine compliance of a data set.

The Characteristic Value approach to determining aggregate compliance offers benefits to producers and purchasers of basecourse aggregates, as follows:

(d) Compliance is determined from a pool of up to 30 test results. This reduces the effect of random non-compliances.
(e) The Characteristic Value approach tolerates some minor individual particle size distribution non-compliances. This means that aggregate should not be rejected on the basis of trivial non-compliant test results.
(f) The Characteristic Value approach assigns risk to producers (that a compliant material is rejected) and consumers (that a non-compliant product is accepted) derived from the Acceptance Constant (k) used to calculate the Characteristic Value. In this instance (and in other Waka Kotahi specifications) the probability of acceptance is set at 90%, while the proportion defective is set at 10%. Refer to Auff (1986) for a full treatment of this approach.

The following charts can be used to monitor the aggregate production. Each sieve is plotted as an individual test result and also as the rolling average of five consecutive results.

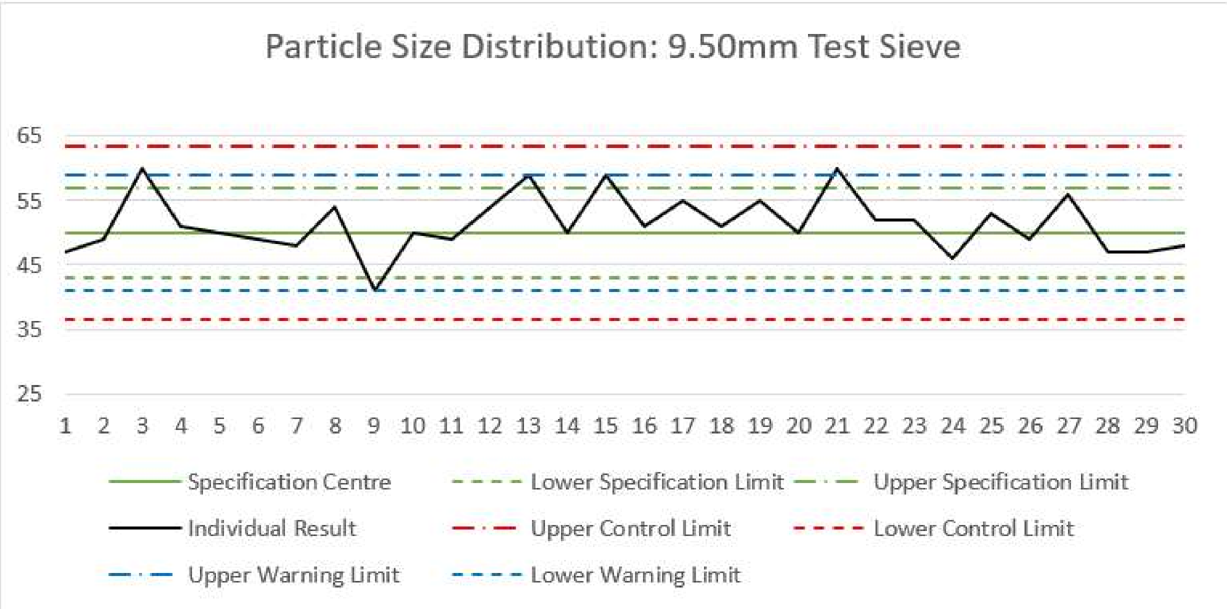

Figure 1: Individual Sieve Process Control Chart

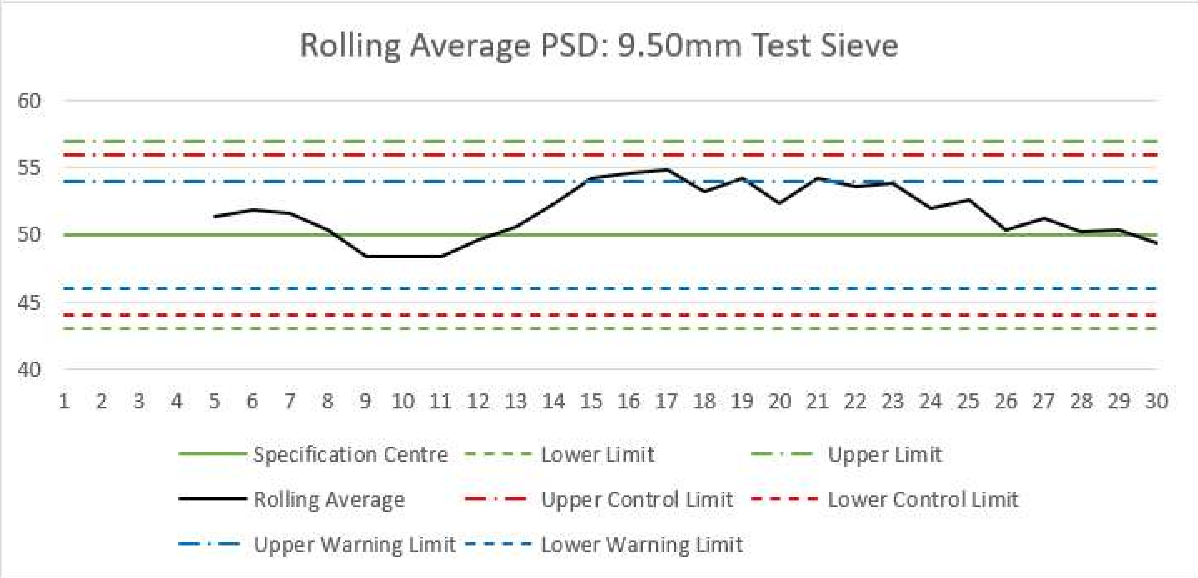

Figure 2: Rolling Average Process Control Chart

3.7.2 Determining Compliance

There are two means of determining if a test, or a set of test results comply with the specification:

(a) If only one test result is reported, then the particle size distribution and the shape control limits must comply with the specified limits appropriate to the aggregate Class
(b) If two or more test results are reported, then the Characteristic Value for the particle size distribution data set must comply with the limits appropriate to the aggregate Class, the curve shape control limits must comply and the compliance score for rolling average 5 test results comply with the particle size limits for the appropriate aggregate Class.

3.7.3 Rolling Averages

There can be random errors in particle size distribution test results arising from stockpile inhomogeneity, sampling effects and testing uncertainties. In order to minimise the effect of such randomness, or "noise" on test results, M04 asks for the rolling average of five consecutive particle size distribution test results to be calculated for each test sieve, and these averages to be compared against the relevant specified size distribution limits. A compliance score is calculated with the requirement being 100% compliance. The intention is that random errors arising from noise in the data should not result in a non-compliance being identified.

4 Regional Aggregates Technical Notes

4.1 General

The requirements of M04, if all just satisfied, produce an acceptable material for nearly all heavy duty flexible pavements. However, where above minimum quality (e.g. stone quality), less severe service conditions (e.g. loading or drainage) occur, or where M04 materials have resulted in poor performance, alternative materials may be used. For assurance with such variants three prerequisites are required:

(a) compensating properties or loadings,
(b) demonstrated (or inferable) performance, and
(c) obtain approval to use an alternative material from the Principal by conducting agreed tests to prove the suitability of the material.

For Waka Kotahi on state highways, the series of approved variants are given in clause 8 of NZTA M04. They include uncrushed and part crushed river source basecourse, and some variants based on rock type and discussion of these variants follows.

4.2 Whanganui Shell Rock

4.2.1 Introduction

Shell Rock is an acceptable regional NZTA M04 material if suitable care is taken with the supply, placement and finishing of the material. It has been used continuously over the last fifty years throughout the Whanganui and South Taranaki regions. Initially the material was quarried and placed directly onto the road, however now it is screened and crushed to provide a more consistent product. The material is self-cementing to varying degrees and works best on more rigid subgrades.

4.2.2 Pavement Investigation

As a result of the tensile characteristics of Shell Rock, pavement investigations should also include measurement of in situ deflection.

Where the Shell Rock is being used as a basecourse in a new pavement construction, the Benkelman Beam deflection should not exceed 2.5mm.

Where the Shell Rock is being used as a pavement overlay, the Benkelman Beam deflection should not exceed 1.5mm.

Where these readings are exceeded, consideration of thicker pavement layers may need to be allowed for.

4.2.3 Pavement Design

The pavement thickness should be designed as a normal unbound NZTA M04 pavement or overlay. Care needs to be taken to ensure underlying materials are not too flexible. Shell Rock should also be treated as a cementitious, bound material to check for cracking in the design and checks made for fatigue failure at the bottom of the Shell Rock layer. Guidance can be found in the New Zealand Supplement to the Austroads Pavement Design Guide. Both the sections on new construction of bound pavements and the design of rehabilitation, particularly the stress dependence of underlying materials (refer asphalt overlays), need to be considered.

Where cracking is likely the pavement may be sealed with an appropriate crack resistant surfacing (such as a geotextile, reinforced polymer seal or a stress absorbing membrane seal).

4.2.4 Construction

Further to NZTA B02 Shell Rock should be laid in layers no thicker than 100mm. Each layer of the pavement is to be fully compacted prior to the placing of subsequent layers. This is to ensure that, as the material is a “softer” material that each layer of a pavement is compacted without over compaction of the top surface of a layer occurring.

As the material is best laid in 100mm layers, consideration of compaction plant required is necessary. After initial compaction with vibratory compaction, consideration should be given to static rolling only to preserve the particle size of the material as much as possible.

Because Shell Rock derives part of its strength from its self-cementing properties, in new construction work it must not be placed in a layer of less than 150mm total thickness. This may require the laying of a thinner layer as the bottom layer, with the upper layer being not less than 100mm.

The material is moisture sensitive, so that care must be taken at all times to ensure that the material is not allowed to become over-saturated with water. Similarly, the Shell Rock will not compact correctly if it is laid too dry.

Shell Rock should not be left on the pavement in a state that is less than fully compacted as it may be prone to rutting. To ensure that each layer is uniformly compacted throughout, all compaction should be applied as soon as possible after placement.

4.2.5 Rehabilitation

Consideration should be given to cracking resistant seals where cracking is the dominant form of distress and the pavement is structurally and functionally sound, i.e. low deflection and little rutting and/or roughness.

4.2.6 Maintenance Operations

Shell Rock is only to be used where the in-situ material adjoining is Shell Rock. It is not to be used as a "make up" material where the thickness of the layer placed is less than 100mm.

Shell Rock is not to be used as a maintenance metal for correcting low shoulder unless the in-situ material is Shell Rock and the material is placed in a layer no less than 100mm thick.

For maintenance overlays, where pavement deflections have been shown to be less than 1.5mm Shell Rock should not be used in layers of less than 120mm.

4.2.7 Advantages

(a) Lower cost than fully M04 compliant materials.
(b) Handled correctly it can be easily laid.
(c) Can provide an excellent surface on which to seal.

4.2.8 Disadvantages

(a) Moisture sensitive, problems if either too wet or too dry.
(b) Should not be trafficked until 95% of compaction has occurred.
(c) Prone to cracking if laid on more flexible subgrades.
(d) Once compacted, it can be difficult to re-grade.

4.3 Taranaki Andesite

4.3.1 Introduction

Taranaki Andesite is the primary Taranaki pavement construction material. Its use has been included as regional variation to NZTA M04 for many years, although the material often does not achieve the 130kN crushing resistance specified.

The material is variable but once compacted in place, performs well. It is therefore appropriate to consider a range of crushing resistance requirements to suit the volume and nature of the traffic loading imposed.

4.3.2 Pavement Investigation

As a minimum, test pits are required for the design of area wide treatments or rehabilitation works. The test pits are to determine the depth and condition of the pavement materials.

4.3.3 Pavement Design

The pavement thickness should be designed as a normal unbound NZTA M04 pavement or overlay. Guidance can be found in the New Zealand Supplement to the Austroads Pavement Design Guide.

4.3.4 Construction

As this material is by its nature, of lesser crushing resistance, the laying operation requires careful monitoring to ensure that minimal damage or breakdown of the material occurs during laying.

The material should be placed layers with a maximum thickness of 150mm and fully compacted prior to the placement of subsequent layers.

4.3.5 Rehabilitation

For pavement rehabilitation operations where stabilising operations are carried out, additional "low fines" material should be added to counteract the breaking down of the material by the hoeing. The material can be either AP40 or AP65 type material.

4.3.6 Maintenance Operations

Taranaki Andesite is only to be used where the adjoining material is similar.

4.3.7 Advantages

(a) Lower cost than fully M04 compliant material
(b) Crushing resistance tailored to suit traffic conditions
(c) Can be easily worked to provide an excellent surface on which to seal.

4.3.8 Disadvantages

(a) Should not be trafficked until 95% of compaction has occurred.
(b) Can be “over worked” and material broken down during laying operation.

4.4 Recycled Crushed Concrete

4.4.1 Introduction

(Modified from web pages of the FHWA Turner Fairbank Highway Research Center, found here)

Recycled Crushed Concrete (RCC) known in the United States as Reclaimed Concrete Material (RCM) can be used as coarse and/or fine aggregate in granular base. The properties of processed RCC generally exceed the minimum requirements for conventional granular aggregates. Being a 100% crushed material, processed RCC aggregates "lock up" well in granular base applications, providing good load transfer when placed on weaker subgrade. The lower compacted unit weight of RCC aggregates compared with conventional mineral aggregates results in higher yield (greater volume for the same weight) and is therefore economically attractive to contractors. For large reconstruction projects, on-site processing and recycling of RCC are likely to result in economic benefits through reduced aggregate hauling costs.

4.4.2 Performance Record

RCC that has been properly processed and tested for appropriate specification compliance has been widely used and has generally demonstrated satisfactory performance in granular base applications. The use of processed RCC as aggregate in base or subbase applications has been accepted by many jurisdictions. Twenty states presently use RCC. They include Arizona, California, Colorado, Florida, Indiana, Iowa, Louisiana, Maryland, Massachusetts, Minnesota, Missouri, Nebraska, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Carolina, and Texas.

Two highway agencies (Illinois and Pennsylvania) have specifications that directly address RCC use in granular base (1). A number of states are conducting or have proposed research into the use of RCC as aggregate for granular base course. They include Arizona, Iowa, Louisiana, Michigan, Missouri, and Nebraska.

Some of the positive features of RCC aggregates in granular base applications include the ability to stabilize wet, soft, underlying soils at early construction stages, good durability, good bearing strength, and good drainage characteristics.

There is recent evidence that the use of some unsuitable or improperly processed RCC aggregate can adversely affect pavement subdrainage systems and pavement performance (2). Tufa-like (white, powdery precipitate) precipitates have been reported by a number of agencies to have clogged subdrains and blinded geotextile filters (2). The tufa precipitate appears to be Portlandite from unhydrated cement and/or calcium carbonate ($CaCO_3$), formed by the chemical reaction of atmospheric carbon dioxide with the free lime (CaO) in the RCC. However, the problem is not universal, and many pavements with RCC granular base are reported to be functioning satisfactorily without any apparent tufa formation.

4.4.3 Material Processing Requirements

(a) Crushing and Screening

Following the initial crushing of concrete rubble in a jaw crusher and removal of any steel by magnetic separation, RCC must be crushed and screened to the desired particle size distribution using conventional aggregate processing equipment.

Where the processed RCC contains some reclaimed asphalt pavement (RAP), which can occur when the RCC is derived from composite pavements, it is recommended that the RAP content in the RCC be limited to 20% maximum to prevent a reduction in bearing strength (3).

(b) Storage

Where RCC is available from different sources or concrete types, it should either be blended or maintained in separate stockpiles to ensure consistent material properties.

(c) Washing

Washing of RCC aggregates is required by some agencies (Ohio, for example) to remove the dust as a measure to reduce potential tufa formation. To control tufa precipitate formation, only suitable RCC that does not contain appreciable unhydrated cement or free lime should be used for granular base applications.

(d) Testing

Additional quality control testing (leachate testing) to assess the tufa precipitate potential of RCC aggregates may be necessary for granular base applications where subdrains are involved. A special procedure to identify the potential for tufa formation in steel slags was developed, which should be appropriate for RCC testing (4).

4.4.4 Engineering Properties

Some of the engineering properties of RCC that are of particular interest when RCC is used as a granular base material include absorption, specific gravity, stability, strength, durability, and drainage.

(a) Absorption

High absorption is particularly noticeable in crushed fine material (minus 4.75mm) derived from air-entrained concrete and ranges between 4% and 8% (compared with 2% or less for virgin concrete aggregates) (7).

(b) Specific Gravity

The specific gravity of RCC aggregates (ranging from 2.0 for fines to 2.5 for coarse particles) is slightly lower than that of virgin aggregates (7).

(c) Stability

RCC has high friction angle, typically in excess of 40° and consequently demonstrates good stability and little post compaction settlement.

(d) Strength Characteristics

Processed RCC, being a 100% crushed material, is highly angular in shape. It exhibits California Bearing Ratio (CBR) values ranging from 90 to more than 140 (depending on the angularity of the virgin concrete aggregate and strength of the Portland cement matrix), which is comparable to crushed limestone aggregates (8,9).

The inclusion of bitumen-coated particles in granular base material leads to reduced bearing capacity, varying with the proportion of bitumen-coated particles. Studies in Ontario, Canada, indicate that bearing strength is reduced below that expected for granular base (using natural aggregate) when the amount of blended bitumen coated particles exceeds 20 to 25% (8).

(e) Durability

RCC aggregates generally exhibit good durability with resistance to weathering and erosion. RCC is non-plastic and is not susceptible to frost.

(f) Drainage Characteristics

RCC (mainly coarse fraction) is free draining and is more permeable than conventional granular material because of lower fines content.

4.4.5 Design Considerations

Standard Austroads pavement structural design procedures can be employed for granular base containing RCC aggregates. It is recommended that the modulus for RCC aggregates should be established by resilient modulus testing.

4.4.6 Construction Procedures

(a) Material Handling and Storage

The same methods and equipment used to store or stockpile conventional aggregates are applicable for RCC. However, additional care is required in stockpiling and handling RCC aggregates to avoid segregation of coarse and fine RCC.

(b) Placing and Compacting

The same methods and equipment used to place and compact conventional aggregate can be used to place and compact RCC.

(c) Special Considerations

Although there do not appear to be any environmental problems associated with leachate from RCC (14,15) some jurisdictions require that stockpiles be separated (a minimum distance) from water courses because of the alkaline nature of RCC leachate.

Where RCC aggregates are used in granular base course applications in conjunction with subdrains, the following procedures are recommended to reduce the likelihood of leachate precipitates clogging the drainage system (7):

(d) Wash the processed RCC aggregates to remove dust from the coarse particles.
(e) Ensure that any geotextile fabric surrounding the drainage trenches (containing the subdrains) does not intersect the drainage path from the base course (to avoid potential plugging with fines).

4.4.7 Unresolved Issues

Further investigation of the propensity for tufa formation of RCC aggregates in granular base is needed. This should also include the development of standard methods to assess the suitability of RCC aggregates for base course applications where subdrains are used.

4.4.8 References

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4.5 Glenbrook Melter Aggregate

4.5.1 Introduction

(Modified from web pages of the FHWA Turner Fairbank Highway Research Center. Additional notes provided by SteelServ Ltd).

Synthetic aggregates produced as co-products from the iron and steel industry have been successfully used internationally for road making for many years and have been the subject of close scrutiny, both from an in-service performance and environmental impact perspective.

It should be noted that the steel industry produces two generic types of slag – one from the iron making process and another from the steel making process. The chemistry of these two slags is considerably different and requires different handling procedures, both during aggregate manufacture and in placement during road construction. Glenbrook Melter Aggregate (GMA) is produced from iron making slag and these notes refer specifically to this product.

The iron and steel industry based at New Zealand Steel's Glenbrook mill is unique by world standards, as it is the only operation manufacturing steel industry products utilizing iron sand as a raw material. As such, the iron making process differs from the industry norm, where blast furnace manufacture from conventional iron ore is the most common iron making production method.

It follows that the chemistry of the iron sand based melter slag is different than conventional blast furnace equivalents (Table 2). The New Zealand Steel product has a high percentage of titanium and higher concentrations of magnesium oxide and aluminium compared to blast furnace slag, while at the other end of the spectrum, the material is low in silicon, calcium oxide and sulphur.

Table 2: Comparison of New Zealand Steel and Blast Furnace Slag Chemistry

Constituent	BFS slag*%	NZ Steel Melter Slag%
CaO	41	14.5
$Si0_2$	35	12
FeT	0.49	4
MgO	6.5	13.6
MnO	0.45	1
TiO_2	1	34.3
Al_20_3	14	17
V_20_3	<0.05	0.2
S	0.6	0.030

Source: Australasian Slag Association and New Zealand Steel analysis

* Often referred to as "Air Cooled Blast Furnace Slag" (ACBFS)

Unlike conventional blast furnace slag, the iron sand based material cannot be granulated, which immediately precludes its use as a cementitious addition in concrete manufacture. Economies of scale prevent other common international uses such as pelletizing, expanding or foaming, to produce light weight aggregates. Conversely, the lower than normal sulphur and calcium oxide content results in a more environmentally acceptable product, with lower pH in leachates and low levels of sulphur. The aggregate also has the ability to remove phosphorous and certain heavy metals when used as a filter material.

Iron making slag can be used as aggregate in granular base applications. It is considered by many international specifying agencies to be a conventional aggregate and can normally exceed the aggregate requirements for granular aggregate base. The high bearing capacity of steel industry slag aggregates can be used advantageously on weak subgrades and in heavy traffic applications. Good interlock between slag aggregate particles provides good load transfer to weaker subgrades. Because of their similar particle shape and angle of internal friction, blast furnace slag aggregates have at times been blended with steel slag aggregates to improve yield, without substantial reduction in stability.

SteelServ Ltd, a joint venture company between New Zealand Steel and Multiserv, an international mill servicing organisation, are responsible for the processing and marketing of the Glenbrook products. Recent up-grades in manufacturing equipment and modern quality control procedures, including the adoption of Multiserv's international "best practice" slag handling procedures, have further improved the aggregates' potential, including the recent acceptance by Waka Kotahi as a skid resistant surfacing.

4.5.2 Performance Record

Glenbrook Melter Aggregate has been used extensively in the greater Auckland area since the late 1980's when the material was first produced. It is estimated that there are approximately 2.5 million tonnes already in use in secondary roading and general construction applications, with a further 500,000 tonnes as drainage products.

Benkelman beam testing of existing roads have shown minimum deflections while Repeat Load Triaxial testing has also demonstrated sound results.

During this period, there have been no observations of expansive properties with this material, although they have been observed from time to time with steel making aggregates, as the latter often contain significant quantities of free lime.

4.5.3 Material Processing Requirements

(a) Quality Control

Iron and steel production is subject to tight quality control procedures to prevent the manufacture of out of specification material and this in turn, reflects in the chemistry and physical properties of the resulting slags. The New Zealand Steel process has remained unchanged for many years, which has resulted in the slag chemistry being stable and consistent. The process is unlikely to change.

International "best practice" quality control procedures for the manufacture of steel industry aggregates are followed by SteelServ and include the segregation of all slags at reception points, the controlled air cooling and watering of materials prior to dig out and the weathering of raw materials in stockpiles for at least six months.

As well as normal aggregate source property and grading testing, SteelServ conducts X-Ray Fluorescence (XRF) analysis to check slag chemistry on every production batch of sub-base and base course aggregate. This means that every time an AP 40 or GAP 65 material is manufactured, an XRF test is conducted on the material prior to sale and checked against the specification limits of Table 3 below:

Table 3: Glenbrook Slag Chemistry Ranges

Element	Minimum %	Maximum %
CaO	10	20
Fe	0	10
SiO_2	9	15
Al_20_3	15	21
MnO	0.5	1.7
MgO	11	15
TiO_2	27	42
Cr_20_3	0.2	0.6
V_2O_5	0.1	0.5

SteelServ also undertakes expansion testing of melter aggregate materials at six monthly intervals as part of regular source property testing.

Stockpiles of finished aggregates are watered to maintain optimum moisture content. The iron making material is relatively free draining compared to naturally occurring equivalents and contains no clays or organic materials.

(b) Crushing and Screening

Prior to use as a granular base material, ferrous components of the melter slag are magnetically separated. Melter slag is then crushed and screened to produce a suitable granular aggregate particle size distribution using processing equipment similar to that for conventional aggregates.

4.5.4 Engineering Properties

Some of the important properties of melter slag that are of particular interest when this material is used as an aggregate in granular base include: specific gravity, stability, durability, corrosivity, volumetric stability, drainage, and iron staining.

(a) Specific Gravity

Due to the relatively high specific gravity of melter slag, the aggregate can be expected to yield a higher density product compared with conventional materials (2.0-2.5).

(b) Stability

Melter slag aggregates have high angle of internal friction (40° to 45°) that contribute to high stability and California Bearing Ratio (CBR) values up to 140 percent.

(c) Durability

Melter slag aggregates display good durability with resistance to weathering and erosion. Weathering Quality Index results range from AA to CA with Aggregate Abrasion Values of surfacing chip ranging from 2.3 – 3.

(d) Corrosivity

The pH value of blast furnace and melter slags aggregate generally ranges from approximately 8 to 10 in laboratory testing. However field observation of leachates and monitoring of melter aggregate filter beds indicates a pH of around 7.5 – 8.0, after hydraulic residence times of two days or more. Blast furnace slags have recorded pH's up to 12.5 in stagnant water and steel making slags can exceed a pH of 11. Therefore in common with blast furnace slags, the leachate of Glenbrook melter slag is generally mildly alkaline and generally does not present a corrosion risk to steel pilings or galvanised steel pipes. However prudent detailing requires galvanised or aluminium pipes not be used in melter slag pavements.

(e) Drainage Characteristics

Melter slag aggregates are free draining and are not susceptible to frost. Contractors need to recognise the free draining characteristics of this material and allow for plenty of water during compaction of subbase or basecourse materials.

(f) Volumetric Instability

Melter slag has no record of expansive properties while in service or under capped conditions. Laboratory testing by Multiserv indicates a free lime content of 0.17% and no expansive properties in autoclave testing. Expansive property testing is part of SteelServ's regular source property examination every six months.

(g) Iron Staining

Drainage from melter slag aggregates can potentially result in mild iron staining of pipes or run-off areas, as a result of small quantities of free iron remaining in the aggregate following manufacture.

4.5.5 Design Considerations

Properly processed melter slag aggregates can readily satisfy particle size distribution requirements and the physical requirements of M04 specification. It is recommended that melter slag be tested for expansion potential in accordance with EN 1744-1:1998.

Granular bases containing melter slag should be designed so that they are well drained (no standing water) and adequately separated from water courses to prevent immersion. Pavement joints should be sealed to minimize the ingress of surface water into the melter slag granular base. These provisions are based on international “Best Practice” for the use of similar materials and are designed to minimize the potential for leaching of iron, manganese or sulphur, which can be observed when these products are subjected to prolonged contact with stagnant water conditions.

Conventional AUSTROADS pavement structural design procedures can be employed for granular base containing melter slag aggregates.

4.5.6 Construction Procedures

(a) Material Handling and Storage

The same general methods and equipment used to handle conventional aggregates are applicable for melter slag.

Stockpiles of processed melter slag aggregate however, should be maintained in a wet condition prior to delivery to the job site to maintain optimum moisture content and to minimise the requirement for additional water use during compaction by the contractor.

(b) Placing and Compacting

The same methods and equipment used to place and compact conventional aggregate can be used to place and compact melter slag. Care is required to avoid placing the material below the water table and in locations where it is likely to be immersed in stagnant water (to avoid potential leachates in stagnant conditions). A good groundwater drainage system is recommended when melter slag aggregate is used to allow free drainage and to prevent ponding within or against the aggregate.

(c) Quality Control

The same field test procedures used for conventional aggregate are recommended for granular base applications when using melter slag. Standard laboratory and field test methods for compacted density are acceptable

4.5.7 Unresolved Issues

In the United States many specifying agencies consider Air-Cooled Blast Furnace Slag to be a conventional aggregate. It is extensively used in granular base, hot mix asphalt, Portland cement concrete, and embankments or fill applications. The material can be crushed and screened to meet specified particle size distribution requirements using conventional aggregate processing equipment. Special quality control procedures may be required to address the lack of consistency in some properties such as particle size distribution, specific gravity, and absorption

Melter slag aggregates have been used extensively in secondary roading applications and in high axle load conditions (150 tonnes plus), for internal roads at New Zealand Steel. The performance characteristics of this material fully meet the requirements of M04 and the performance of similar aggregates internationally indicate a sound material for major road construction.

Continued monitoring of pavements constructed with this material will be required to further establish long term performance characteristics and should include deflection testing, rut testing and observation of any environmental impacts.

4.5.8 Further Information

Australasian Slag Association
www.asa-inc.org.au

National Slag Association, USA
Email: useslag@trip.net

New Zealand Steel Ltd
https://www.nzsteel.co.nz/products/aggregates/

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4.6 Aggregate and Reclaimed Glass Blends

4.6.1 Introduction

There is currently an issue of over-supply of reclaimed glass in most areas of New Zealand. The objective of incorporating a small proportion of reclaimed glass (cullet) in basecourse aggregate is to allow local authorities to eliminate current stockpiles of reclaimed glass, and to manage ongoing supplies of reclaimed glass, in a positive fashion. The alternative is most likely dumping of reclaimed glass in landfills, a process that is costly and environmentally unattractive.

This addition to the M04 specification has been made without detailed materials testing. The approach that has been adopted has been to review the recent technical literature regarding the use of reclaimed glass in unbound aggregates overseas and to implement a conservative specification, at least until local research results and/or performance records have been established.

4.6.2 Cullet Proportion

According to UNH (2000), experience has shown that the properties of aggregate/cullet blends containing up to 20% cullet do not differ substantially from the properties of the aggregate alone.

Massachusetts and Minnesota DOTs allow up to 10% cullet, FHWA recommends up to 15% (30% in subbase applications) and California DOT allows up to 50% cullet (UNH, 2000). Therefore, Waka Kotahi is confident that the 5% cullet allowed in M04 is sufficiently conservative that the quality of premium basecourse will not be compromised in any way. Furthermore, the 5% allowable cullet proportion is considered to be reasonable given that the quantity of excess reclaimed glass in New Zealand is relatively minor.

4.6.3 Cullet Origins

The allowable origins for the cullet specified in M04 are largely based on the criteria established by Minnesota DOT (MnDOT, undated). The objective is to provide relatively consistent cullet properties with favourable particle size distribution and particle shape parameters. In addition, the cullet must not present any environmental issues with respect to releasing potentially harmful materials to adjacent land or water courses. This is the reason why cathode ray tubes are generally excluded in cullet specifications.

Some specifiers require glass strength or durability criteria to be met. Waka Kotahi does not consider this to be necessary given the expected uniformity of the cullet and the relatively low cullet proportion in the aggregate.

4.6.4 Particle Size Distribution

Crushing reclaimed glass is reported to be somewhat more difficult than for conventional aggregates (Taylor, 2006 personal communications). However, crushing provides the benefit of producing a continuously graded product that can be readily blended with natural aggregate. The crushing and agitation process also removes the sharp edges from the glass.

The particle size distribution provided in M04 originated from the Massachusetts DOT cullet specification. The 9.5mm maximum particle size is considered to provide an appropriate compromise between cost-effective crushing and providing sufficient agitation to produce a product that is safe to handle.

The particle shape requirement that limits elongated particles (i.e., greater than 5:1 maximum to minimum particle dimensions) to a maximum of 1% for cullet retained on the 4.75mm sieve is provided for both safety and performance reasons.

4.6.5 Contamination Limits

Contamination of cullet with paper, plastic, metal, corks, etc, is arguably one of the more difficult aspects of utilizing reclaimed glass. This is especially true for the New Zealand market where the quantity of reclaimed is relatively small and processing operations are relatively basic.

The literature is somewhat inconsistent regarding the allowable limits for contamination. Some specifications call for a blanket limit of <5% debris by mass while others provide specific limits for various types of debris (e.g. AASHTO M 318-01).

Quantifying the level of contamination is also debatable, with procedures based on both mass and volume bases being specified. The RMS T276 method (based on mass of debris) has been adopted as it is less subjective than equivalent volumetric procedures. In addition, it has been adopted in the M04 specification for recycled crushed concrete (RCC). Note that the T276 test was specifically written for RCC so the user must substitute “reclaimed glass” for “RCC”.

The 5% blanket contamination criterion is considered to be appropriate, at least in the interim, considering the relatively low proportion of cullet that is allowed in the aggregate blend.

4.6.6 Cleanliness

It is recognized that odour can be an issue where reclaimed glass has not been washed by the consumer or by the collection contractor. However, it is not possible to specify a cleanliness criterion, other than to state that the reclaimed glass supplier must ensure that the cullet is properly cleaned and does not produce an odour problem.

4.6.7 Production

The aggregate / cullet blend must be thoroughly mixed to ensure that the cullet does not end up in pockets or lenses within the basecourse layer where it would compromise the mechanical properties of the material. Given the relatively low allowable proportion of reclaimed glass, adequate mixing should be achievable by simply using a loader at the stockpile.

4.6.8 Quality Assurance Test Frequency

The main issues with reclaimed glass are grading, particle shape and contamination. The M04 specification states that a test frequency of at least two tests for each parameter should be undertaken per cullet stockpile. This frequency may be able to be relaxed in time as production experience increases.

4.6.9 Unresolved Issues

There are a number of unresolved issues relating to the use of reclaimed glass in basecourse aggregates. However, these issues diminish somewhat at the low proportion of reclaimed glass allowed in the M04 specification. Areas that require further research include:

(a) effect of cullet on cement and / or bitumen treatment
(b) effect of cullet on adhesion of bituminous surfacings, and
(c) potential to increase the proportion of cullet in the basecourse blend.

These issues will be resolved as appropriate research becomes available.

4.6.10 References

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