TNZ M/4 NOTES: 2006

NOTES TO THE SPECIFICATION FOR BASECOURSE AGGREGATE

These notes are for the guidance of supervising offices and must not be included in the Contract Documents.

1. SCOPE

TNZ M/4 is the reference or standard specification for primary basecourse for heavy duty use in flexible pavements with thin surfacings.

Use of the term *"basecourse"* should be restricted to only select quality material suitable for the uppermost granular layer adjacent to the surfacing.

Lower layers, where performance requirements allow a lesser quality material, should be referred to and specified as *"subbase"*. Given the variation in materials available from place to place for subbase use, there is no standard specification, but M/3 Notes sets out the recommended procedure for local specification development, with examples to illustrate preferred format.

The requirements of M/4, if all just satisfied, produce an acceptable material for nearly all heavy duty flexible pavements. However, where above minimum quality (eg stone quality), less severe service conditions (eg loading or drainage) occur, or where M4 materials have resulted in poor performance, alternative specifications may well be in order. For assurance with such variants two prerequisites are required:

(i) compensating properties or loadings,

(ii) demonstrated (or inferable) performance, and

(iii) obtain approval to use an alternative material from Transit New Zealand's Engineering Policy Manager by conducting agreed tests to prove the suitability of the material.

For Transit New Zealand on state highways, the series of approved variants are given in Table 4 of TNZ M/4. They include uncrushed and part crushed river source basecourse, and some variants based on rock type.

Roading Contract Documents should include a requirement that the Contractor must state the source of his aggregate.

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2. TESTING

Section 2 requires that each individual sample must meet the specification. Before the Contractor can be brought to task for failing to meet the specification it is important to ensure that testing is carried out strictly according to the standard methods specified. Care should be taken when sampling to ensure that the sample is representative of a significant amount of material.

All the tests specified should be carried out for acceptance testing.

Acceptance testing comprises of both source material testing and production (quality control) testing.

(a) Source material testing - tests such as crushing resistance, weathering resistance and to a certain extent sand equivalent indicate basic inherent properties of the rock.

(b) Production (quality control) testing - tests such as particle-size distribution, proportion of broken rock and sand equivalent indicate how the production process, and variations of it, affects the product.

When large amounts of material are being supplied the following procedure should be adopted:

(i) Source material testing establishes the basic rock properties.

(ii) Production testing is then regularly carried out to monitor the product.

(iii) Source material testing is occasionally carried out to check the material properties, in particular when a change in material or properties is suspected. (eg: when a seam containing clay is encountered).

The size of the representative sample required depends on what tests are actually going to be carried out. Therefore constant liaison between the testing laboratory and the officer doing the sampling is necessary. (Preferably someone from the testing laboratory should do the sampling but this is often impractical). "When" samples are being taken, it should be understood "why" they are being taken.

In general the material used for the particle-size distribution test can subsequently be used in other tests.

Several tests require test samples which comprise of material in specific particle-size ranges. Hence the mass of a representative sample from which a given mass of test sample can be obtained is dependant on the grading of the representative sample.

The following indicates sample sizes required for particular tests:

TEST	M/4 GRADING	MINIMUM TEST SAMPLE MASS (kg)	REPRESENTATIVE SAMPLE (quartered etc to obtain test sample) (kg)
Particle-size distribution NZS 4407 : 1991 Test 3.8.1	AP40	10	40
Particle-size distribution NZS 4407 : 1991 Test 3.8.1	AP20	5	20

TEST	PARTICLE-SIZE RANGE FOR TEST SAMPLE (mm)	MINIMUM TEST SAMPLE MASS (kg)	REPRESENTATIVE SAMPLE (sieved to obtain test sample) (kg)
Sand equivalent NZS 4407 : 1991 Test 3.6	passing 4.75	0.5	* approx 2
Crushing resistance NZS 4407 : 1991 Test 3.10	13.2 - 9.5	8	* approx 50
Weathering resistance NZS 4407 : 1991 Test 3.11	19.0 - 9.5 9.5 - 4.75	2 3	* approx 30

* These approximate figures assume the representative sample has an M/4 grading.

3. PROPORTION OF BROKEN ROCK

The specified proportion, for each size fraction, is designed to define materials that will have properties that effectively match a quarried product.

4. CRUSHING RESISTANCE

This test indicates the ease of processing (strength) of the aggregate and the likelihood of attrition. Although materials which have a crushing resistance less than 130 kN cannot be classified as M/4 basecourse this does not necessarily preclude their use where stronger aggregates are not available. The use of these materials however will require other specification changes, representing a significant departure from the Transit New Zealand standard pavement design procedure.

Conversely experience with local aggregates may show that a minimum crushing resistance greater than 130 kN is necessary to ensure a material with adequate strength.

5. WEATHERING RESISTANCE

This test is an accelerated laboratory test to assess the resistance of aggregate to the combined agencies of wetting and drying, and heating and cooling. Thus it is some measure of soundness and durability.

It is recognised that the test is far from ideal for ensuring the durability of an aggregate in service, and the meaning of the results is far from certain. It is however the best of many inadequate tests and will have to serve till something better is developed.

6. SAND EQUIVALENT

This test measures the relative amounts of silt or clay-size particles in granular soils. Thus it indicates cleanness.

Although the sand equivalent test has replaced the plasticity index test the two are not strictly comparable. The deleterious effect of the presence of clay fractions is to seriously reduce the aggregate's permeability and increase its susceptibility to stability destroying pore pressures. The object of the specification is to control the proportion of such ultrafine material in the fine aggregate and the sand equivalent test does this satisfactorily.

7. GRADING

An alternative grading has been added to the specification. This grading AP20 (all passing 20 mm) has a topsize of 19 mm and is intended for use in thin granular overlays.

Non structural, shape restoring overlays require the minimum depth of metal over high spots with sufficient depth over low spots to provide an acceptable riding surface. The minimum depth of metal over high spots will depend primarily on the maximum particle size of the material and considerable savings are possible if the maximum size is 19 mm instead of the standard 37.5 mm.

Limits on use of AP20 basecourse:

(i) Not less than 40 mm over high spots - to ensure satisfactory workability and compactibility.

(ii) Not more than 125 mm depth in depressions - to ensure adequate stability.

(iii) In some areas AP20 basecourse may cost significantly more per cubic metre than AP40 basecourse. In such cases a decision on which material to use should be based on the overall economics, bearing in mind that a smaller quantity will be required of the AP20 material.

The AP40 and AP20 nomenclature is consistent with the recommendations for aggregate naming of the Aggregates Association of New Zealand. AP40 and AP20 refer only to the size of the material and not the quality. To specify these materials TNZ M/4 AP40 and TNZ M/4 AP20 must be quoted.

With the gradings shown it will normally be unnecessary to choke the basecourse surface with additional fines.

Where an AP40 aggregate has a much higher than minimum crushing resistance, the standard grading, which includes provision for some gradation change during compaction, may accept materials that appear deficient in fines during construction. In such a case it is proper to vary the specified grading by adding an amending clause to the job specification. A suitable such clause is:

"For basecourse produced from "named material type" the gradation requirements shall be varied for the specific sieve apertures tabulated below."

TEST SIEVE APERTURE	PERCENT PASSING (AP40)
300 µm	5 - 14
150 µm	3 - 10
75 µm	2 - 7

This change effectively bars materials with nothing finer than 300 µm.

Such a provision is not necessary with AP20 aggregate as it is used in thin layers (less breakdown under compaction) and its grading already includes adequate fine material.

The grading shape control sets limits to local deviations from the general shape of the grading envelope.

8. BASIS OF MEASUREMENT AND PAYMENT

Although the specification stipulates that the issue of a cartage docket is not an acceptance that the material supplied complies with specification requirements, the tallyman should be supplied with typical quality control samples so as to avoid as much as possible the need to condemn substandard aggregate after it has been delivered. However, it should also be emphasised that it is not proper to expect a tallyman to carry substantial authority in this matter, and constant liaison will often be necessary.

M/4 is written on the basis of payment by volume at the point of delivery.

It may be more convenient to supply the aggregate by weight by using TNZ G/2 *"Conditions for Supply of Aggregate by Weight"*.

G/2 applies when the supply of aggregate is a separate contract item and the quantity for payment purposes is specified as the loose volume in delivery trucks. Payment will be made on the volume delivered to the delivery point but the purchaser may agree to the use of a mass per unit volume conversion factor to give delivered volume from certified weights.

APPENDIX 1

WANGANUI SHELL ROCK TECHNICAL NOTE

INTRODUCTION

Shell Rock is an acceptable regional TNZ M/4 material where 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 Wanganui / South Taranaki area. 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.

PAVEMENT INVESTIGATION

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

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

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

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

PAVEMENT DESIGN

The pavement thickness shall be designed as a normal unbound TNZ M/4 pavement or overlay. Care needs to be taken to ensure underlying materials are not too flexible. Shell Rock shall also be treated as a cementitiously-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 SAM Seal).

CONSTRUCTION

Further to TNZ B/2:1997, 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 150 mm 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. Nor will the Shell Rock 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 wheel rutting. To ensure that each layer is uniformly compacted throughout, all compaction should be applied as soon as possible after laying

REHABILITATION

Consideration should be given to SAM 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).

MAINTENANCE OPERATIONS

Shell Rock is only to be used where the insitu 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 100 mm.

Shell Rock is not to be used as a maintenance metal for correcting low shoulder unless the insitu material is Shell Rock and the material is placed in a layer no less than 100 mm 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 120 mm.

ADVANTAGES

1. Lower cost than fully M/4 compliant materials.
2. Handled correctly it can be easily laid.
3. Can provide an excellent surface on which to seal.

DISADVANTAGES

1. Moisture sensitive, problems if either too wet or too dry.
2. Should not be trafficked until 95% of compaction has occurred.
3. Prone to cracking if laid on more flexible subgrades.
4. Once compacted, it can be difficult to re-grade.

APPENDIX 2

TARANAKI ANDESITE TECHNICAL NOTE

INTRODUCTION

Taranaki Andesite is the primary Taranaki pavement construction material. Its use has been included as regional variation to TNZ M/4 for many years, although the material struggles to achieve the 130 kN 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.

PAVEMENT INVESTIGATION

As a minimum, test pits are required for the design of Area Wide Treatments or Rehabilitation works. The test pits are to be dug to determine the depth and condition of the pavement materials.

PAVEMENT DESIGN

The pavement thickness shall be designed as a normal unbound TNZ M/4 pavement or overlay. Guidance can be found in the New Zealand Supplement to the Austroads Pavement Design Guide.

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 150 mm and fully compacted prior to the placement of subsequent layers.

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.

MAINTENANCE OPERATIONS

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

ADVANTAGES

1. Lower cost than fully M/4 compliant material
2. Crushing resistance tailored to suit traffic conditions
3. Can be easily worked to provide an excellent surface on which to seal.

DISADVANTAGES

1. Should not be trafficked until 95% of compaction has occurred.
2. Can be "over worked" and material broken down during laying operation.

APPENDIX 3

RECYCLED CRUSHED CONCRETE TECHNICAL NOTE

(modified from web pages of the FHWA Turner Fairbank Highway Research Center)

INTRODUCTION

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 RCM generally exceed the minimum requirements for conventional granular aggregates. Being a 100 percent crushed material, processed RCM aggregates "lock up" well in granular base applications, providing good load transfer when placed on weaker subgrade. The lower compacted unit weight of RCM 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 RCM are likely to result in economic benefits through reduced aggregate hauling costs.

PERFORMANCE RECORD

RCM 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 RCM as aggregate in base or subbase applications has been accepted by many jurisdictions. Twenty states presently use RCM. 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 RCM use in granular base.(1) A number of states are conducting or have proposed research into the use of RCM as aggregate for granular base course. They include Arizona, Iowa, Louisiana, Michigan, Missouri, and Nebraska.

Some of the positive features of RCM 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 RCM 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 RCM. However, the problem is not universal, and many pavements with RCM granular base are reported to be functioning satisfactorily without any apparent tufa formation.

MATERIAL PROCESSING REQUIREMENTS

Crushing and Screening
Following the initial crushing of concrete rubble in a jaw crusher and removal of any steel by magnetic separation, RCM must be crushed and screened to the desired gradation using conventional aggregate processing equipment.

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

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

Washing
Washing of RCM 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 RCM that does not contain appreciable unhydrated cement or free lime should be used for granular base applications.

Testing
Additional quality control testing (leachate testing) to assess the tufa precipitate potential of RCM 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 RCM testing.[4]

ENGINEERING PROPERTIES

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

Absorption: High absorption is particularly noticeable in crushed fine material (minus 4.75 mm (No. 4 sieve)) derived from air-entrained concrete and ranges between 4 and 8 percent (compared with 2 percent or less for virgin concrete aggregates).[7]

Specific Gravity: The specific gravity of RCM aggregates (ranging from 2.0 for fines to 2.5 for coarse particles) is slightly lower than that of virgin aggregates.[7]

Stability: RCM has high friction angle, typically in excess of 40^{o} and consequently demonstrates good stability and little postcompaction settlement.

Strength Characteristics: Processed RCM, being a 100 percent 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 asphalt-coated particles in granular base material leads to reduced bearing capacity, varying with the proportion of asphalt-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 asphalt coated particles exceeds 20 to 25 percent.[8]

Durability: RCM aggregates generally exhibit good durability with resistance to weathering and erosion. RCM is nonplastic, and is not susceptible to frost.

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

DESIGN CONSIDERATIONS

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

CONSTRUCTION PROCEDURES

Material Handling and Storage

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

Placing and Compacting

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

Special Considerations

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

Where RCM 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)

- Wash the processed RCM aggregates to remove dust from the coarse particles.
- 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).

UNRESOLVED ISSUES

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

REFERENCES

1. Collins, R. J. and S. K. Cielieski. *Recycling and Use of Waste Materials and By-Products in Highway Construction*, National Cooperative Highway Research Program Synthesis of Highway Practice 199, Transportation Research Board, Washington, 1994.

2. Gupta, J. D. and W. A. Kneller. *Precipitate Potential of Highway Subbase Aggregates,* Report No. FHWA/OH-94/004 prepared for the Ohio Department of Transportation, November 1993.

3. Hanks, A. J. and E. R. Magni. *The Use of Recovered Bituminous and Concrete Materials in Granular Base and Earth,* Ontario Ministry of Transportation Report MI-137, Downsview, Ontario, 1989.

4. Gupta, J. D., W. A. Kneller, R. Tamirisa, and E. Skrzypczak-Jankun. "Characterization of Base and Subbase Iron and Steel Slag Aggregates Causing Deposition of Calcareous Tufa in Drains," *Transportation Research Record No. 1434,* 1994.

5. American Association of State Highway and Transportation Officials. Standard Specification for Materials, "Aggregate and Soil-Aggregate Subbase, Base and Surface Courses," AASHTO Designation: M147-70 (1980), Part I Specifications, 14th Edition,1986.

6. American Society for Testing and Materials. Standard Specification D2940-92, "Graded Aggregate Material for Bases and Subbases for Highways or Airports," Annual Book of ASTM Standards, Volume 4.03, West Conshohocken, Pennsylvania, 1996.

7. ACPA. *Concrete Paving Technology: Recycling Concrete Pavement,* American Concrete Pavement Association, Illinois, 1993.

8. Senior, S. A. S. I. Szoke, and C. A. Rogers, "Ontario's Experience with Reclaimed Materials for Use as Aggregates," Presented at the International Road Federation Conference, Calgary, Alberta, 1994.

9. Petrarca, R.W. and V.A. Galdiero, "Summary of Testing of Recycled Crushed Concrete," *Transportation Research Board No. 989,* pp. 19-26, Washington, D.C., 1984.

10. American Association of State Highway and Transportation Officials. Standard Method of Test, "Density of Soil In-Place by the Sand Cone Method," AASHTO Designation: T191-86, Part II Tests, 14th Edition, 1986.

11. American Association of State Highway and Transportation Officials. Standard Method of Test, "Density of Soil In-Place by the Rubber-Balloon Method," AASHTO Designation: T205-86, Part II Tests, 14th Edition, 1986.

12. American Association of State Highway and Transportation Officials. Standard Method of Test, "Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)," AASHTO Designation: T238-86, Part II Tests, 14th Edition, 1986.

13. American Association of State Highway and Transportation Officials. Standard Method of Test, "Moisture Content of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)," AASHTO Designation: T239-86, Part II Tests, 14th Edition, 1986.

14. Kreitch, A.J. *Leachability of Asphalt and Concrete Pavements,* Heritage Research Group Report, Indianapolis, Indiana, March 1992.

15. IGGA. *Grinding Slurry Analysis,* International Grooving and Grinding Association, Skyland, November 1990.

APPENDIX 4

GLENBROOK MELTER SLAG AGGREGATE TECHNICAL NOTE

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

INTRODUCTION

Synthetic aggregates produced as co-products from the iron and steel industry have been sucessfully 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 proceedures, both during aggregate manufacture and in placement during roading construction. Glenbrook Melter Slag is an 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 ironsand 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 1). The New Zealand Steel product has a high percentage of titanium and higher concentrations of magnesium oxide and aluminum compared to blast furnace slag, while at the other end of the spectrum, the material is low in silicon, calcium oxide and sulphur.

Table 1: Comparison of New Zealand Steel and Blast Furnace Slag Chemistry

Constituent	BFS slag* %	**NZ Steel Melter Slag %**
CaO	41	**14.5**
Si02	35	**12**
FeT	0.49	**4**
MgO	6.5	**13.6**
MnO	0.45	**1**
TiO2	1	**34.3**
Al203	14	**17**
V203	<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 cementious addition in concrete manufacture. Economy's 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 proceedures, including the adoption of Multiserv's international "best practice" slag handling proceedures, have further improved the aggregates's potential, including the recent acceptance by Transit New Zealand as a skid resistant surfacing.

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.

Benklemen beam testing of existing roads have shown minimum deflecations 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.

MATERIAL PROCESSING REQUIREMENTS

Quality Control

Iron and steel production is subject to tight quality control proceedures 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 proceedures for the manufacture of steel industry agggregates are followed by SteelServ and include the segregation of all slags at reception points, the contolled 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 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 2 below:

Table 2: Glenbrook Slag Chemistry Ranges

Element	Min %	Max %
CaO	10	20
Fe	0	10
Sio2	9	15
Al203	15	21
MnO	0.5	1.7
MgO	11	15
TiO2	27	42
Cr203	0.2	0.6
V2O5	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 occuring equivalents and contains no clays or organic materials.

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 gradation using processing equipment similar to that for conventional aggregates.

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.

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 mixes (2.0-2.5).

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.

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.

Corrosivity: The pH value of blast furnance 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 furnance slags have recoreded pH's up to 12.5 in stagnent 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 aluminum pipes not be used in melter slag pavements.

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

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 nil expansive properties in autoclave testing. Expansive property testing is part of SteelServ's regular source property examination every six months.

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.

DESIGN CONSIDERATIONS

Properly processed melter slag aggregates can readily satisfy gradation requirements and the physical requirements of TNZ M/4. 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, managnese 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.

CONSTRUCTION PROCEDURES

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.

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.

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

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 gradation requirements using conventional aggregate processing equipment. Special quality control procedures may be required to address the lack of consistency in some properties such as gradation, 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 requiremnets of M4 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 charcteristics and should include deflection testing, rut testing and observation of any environmental impacts.

FURTHER INFORMATION

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1. Mineral Commodity Summaries 1993. Bureau of Mines, U.S. Department of the Interior, Washington, DC, 1993.

2. Collins, R.J. and S.K. Ciesielski. *Recycling and Use of Waste Materials and By-Products in Highway Construction*. National Cooperative Highway Research Program Synthesis of Highway Practice 199, Transportation Research Board, Washington, DC, 1994.

3. American Association of State Highway and Transportation Officials. Standard Specification for Materials, "Blended Hydraulic Cements," AASHTO Designation: M240-85, Part I Specifications, 14th Edition, 1986.

4. American Association of State Highway and Transportation Officials. Standard Specification for Materials, "Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars," AASHTO Designation: M302-86, Part I Specification, 14th Edition, 1986.

5. Recovered Materials Advisory Notice (RMAN). Environmental Protection Agency, *Federal Register*, May 1, 1995.

6. NSA 188.1. *Processed Blast Furnace Slag, The All Purpose Construction Aggregate*, National Slag Association, Alexandria, Virginia.

7. Emery, J.J. "Pelletized Lightweight Slag Aggregate," *Proceedings of Concrete International 1980*, Concrete Society, April, 1980.

8. Fax memorandum, S. Szoke, Ontario Ministry of Transportation to D. Horvat, National Slag Limited, April 7, 1995.

9. *Mineral Aggregate Conservation Reuse and Recycling*. Report prepared by John Emery Geotechnical Engineering Limited for Aggregate and Petroleum Resources Section, Ontario Ministry of Natural Resources. Ontario, 1992.

10. NSA 166.2. "Blast Furnace Slag, Ideal Backfill Material for Steel Sheet Piling," National Slag Association, Alexandria, Virginia.

11. Short, A. "The Use of Lightweight Concrete in Reinforced Concrete Construction," *The Reinforced Concrete Review*, British Reinforced Concrete Association, Vol.5, No.3, September 1959.

12. National Slag Limited. Letter, April 4, 1995, D. Horvat, National Slag Limited to P. Verok, MTO Construction Office, with Attachment, Overview Report, Leachate Mechanism, Blast Furnace Slag Technical Committee, Hamilton, Ontario, March 17, 1995.

13. BQSF. *Report of the Visit of the Slag Study Group of the Japan Iron and Steel Federation of BQSF*, British Quarrying and Slag Federation Limited, June 29, 1978.

14. BSI. British Standard Specification for Air-Cooled Blastfurnace Slag Aggregate for Use in Construction, BS 1047: 1983, British Standards Institution, 1983.

15. NSL. *The Leaching of Sulphur from Blast Furnace Slag*, National Slag Limited, November, 1985.

16. Nordrhein-Westfalen. *Requirements for the Use of Processed Recycled Construction Materials and Industrial By-Products for Excavation and Road Construction from the Standpoint of Water Management*, (Dofasco translation), Ministerial Publication 45,

State of Nordrhein-Westfalen, July 18, 1991.

17. JIS. I*ron and Steel Slag for Road Construction*, JIS A 5015, Japanese Industrial Standards, 1992.

18. ASA. *Guide to the Use of Slag in Roads*, Australian Slag Association, 1994.

19. Ohio EPA. "Interim Policy: Use of Blast Furnace and Steel Slag," State of Ohio Environmental Protection Agency, June 6, 1994.

20. Noureldin, A. S. and R. S. McDaniel. "Evaluation of Steel Slag Asphalt Surface Mixtures", Presented at the 69th Annual Meeting, Transportation Research Board, Washington, January, 1990.

21. Smith, M. A., *Resources Policy*, Vol. 1, No. 3, pp. 154-170, 1975.

22. Australasian Slag Association (ASA), 2002, A Guide to the Use of Slag in Roads. Revision 2. Australasian Slag Association Inc., Wollongong, NSW 2500, Australia.

23. BS1047:1983 Specification for air cooled blast furnace slag aggregates for use in construction.

24. Byers G.C., Saleh M.F., and Pidwerbesky B.D., 2004, Evaluation of Melter Slag as a Base Course Material. The International Journal of Pavement Engineering, Vol.5 (4), December 2004 pp.193-199

APPENDIX 5

AGGREGATE / RECLAIMED GLASS BLENDED BASECOURSE

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 M/4 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.

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, Transit New Zealand is confident that the 5% cullet allowed in M/4 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.

CULLET ORIGINS

The allowable origins for the cullet specified in M/4 are largely based on the criteria established by Minnesota DOT (MnDOT, undated). The objective is to provide relatively consistent cullet properties with favourable grading 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. Transit New Zealand does not consider this to be necessary given the expected uniformity of the cullet and the relatively low cullet proportion in the aggregate.

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 M/4 originated from the Massachusetts DOT cullet specification. The 9.5 mm 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 4.75 mm sieve is provided for both safety and performance reasons.

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 RTA T276 (2001) 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 M/4 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.

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.

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.

QUALITY ASSURANCE TEST FREQUENCY

The main issues with reclaimed glass are grading, particle shape and contamination. The M/4 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.

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 M/4 specification. Areas that require further research include:

- effect of cullet on cement and / or bitumen treatment;
- effect of cullet on adhesion of bituminous surfacings; and,
- potential to increase the proportion of cullet in the basecourse blend.

These issues will be resolved as appropriate research becomes available.

REFERENCES

AASHTO (undated) “Standard Specification for Soil-Aggregate Base Course”, AASHTO Designation M 318-01.

MnDOT (undated) “Aggregate for Surface and Basecourses”, Minnesota Department of Transportation.

RTA (2001) “Foreign Materials Content of Recycled Crushed Concrete”, Test Method T276, RTA New South Wales.

Taylor, B. (2006) Personal communications.

UNH (2000) “White Paper and Specification for Glass Cullet Use For Soil Aggregate Base Course”, Project 13: Development and Preparation of Specifications for Recycled Materials in Transportation Applications, University of New Hampshire.