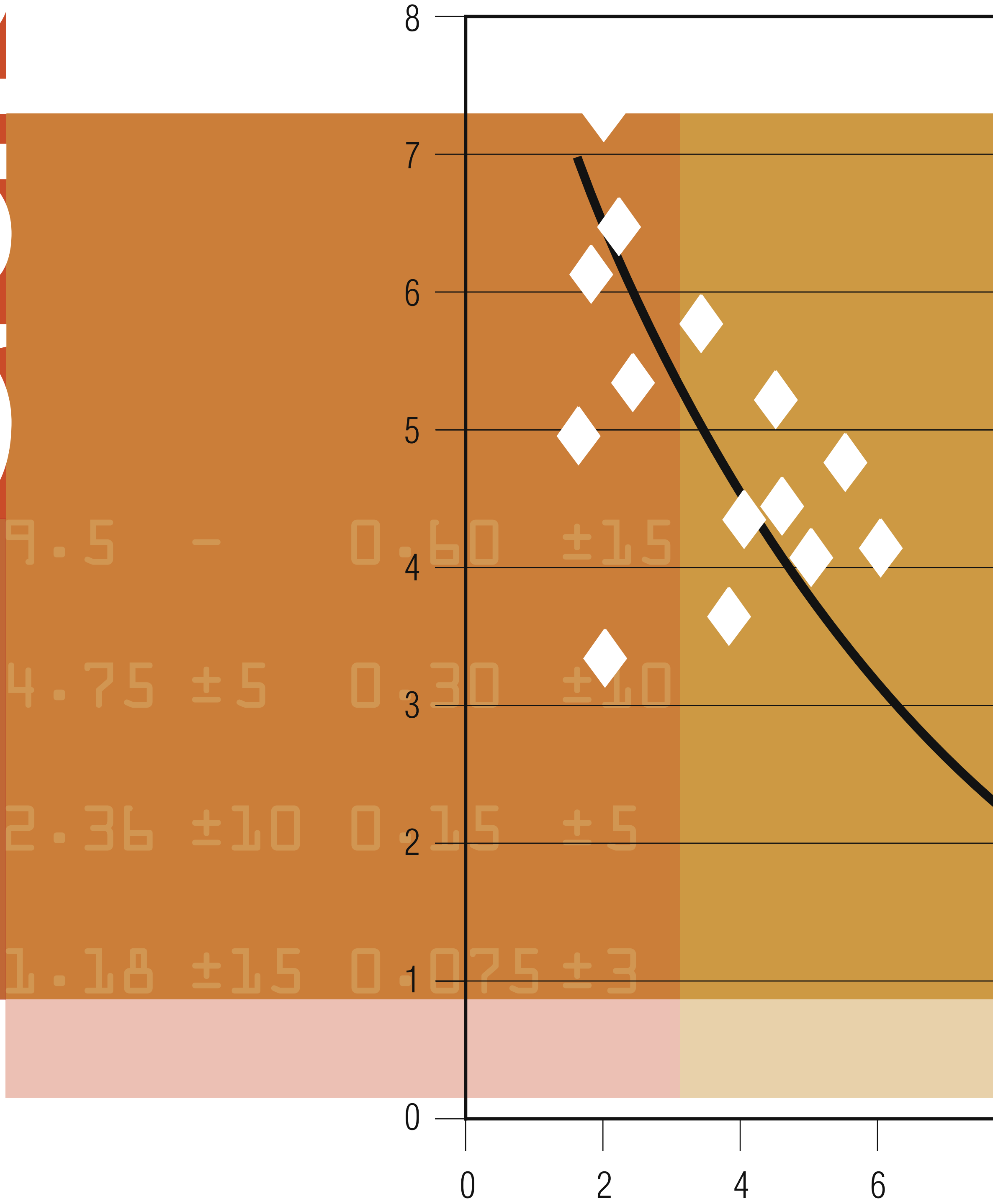
CCAA T60

Guide

Guide to the Specification and Use of Manufactured Sand in Concrete



CEMENT CONCRETE
& AGGREGATES AUSTRALIA

Guide

Guide to the Specification and Use of Manufactured Sand in Concrete

Cement Concrete & Aggregates Australia

First published November 2008

CCAA T60

DESIGN AND LAYOUT Helen Rix Design

ISBN 978-1-877023-25-5

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

Cement Concrete & Aggregates Australia is a not-for-profit organisation established in 1928 and committed to serving the Australian construction community.

CCAA is acknowledged nationally and internationally as Australia's foremost cement and concrete information body – taking a leading role in education and training, research and development, technical information and advisory services, and being a significant contributor to the preparation of Codes and Standards affecting building and building materials.

CCAA's principal aims are to protect and extend the uses of cement, concrete and aggregates by advancing knowledge, skill and professionalism in Australian concrete construction and by promoting continual awareness of products, their energy-efficient properties and their uses, and of the contribution the industry makes towards a better environment.

Cement Concrete & Aggregates Australia
ABN 34 000 020 486

CCAA OFFICES

SYDNEY OFFICE:
Level 6, 504 Pacific Highway
St Leonards NSW Australia 2065
POSTAL ADDRESS:
Locked Bag 2010
St Leonards NSW 1590
TELEPHONE: (61 2) 9437 9711
FACSIMILE: (61 2) 9437 9470

BRISBANE OFFICE:
Level 14, IBM Building
348 Edward Street
Brisbane QLD 4000
TELEPHONE: (61 7) 3831 3288
FACSIMILE: (61 7) 3839 6005

MELBOURNE OFFICE:
2nd Floor, 1 Hobson Street
South Yarra VIC 3141
TELEPHONE: (61 3) 9825 0200
FACSIMILE: (61 3) 9825 0222

PERTH OFFICE:
45 Ventnor Avenue
West Perth WA 6005
TELEPHONE: (61 8) 9389 4452
FACSIMILE: (61 8) 9389 4451

ADELAIDE OFFICE:
Greenhill Executive Suites
213 Greenhill Road
Eastwood SA 5063
POSTAL ADDRESS:
PO Box 229
Fullarton SA 5063
TELEPHONE: (61 8) 8274 3758
FACSIMILE: (61 8) 8373 7210
EXTRACTIVE INDUSTRIES AND
PREMIXED CONCRETE OFFICE
PO Box 243
Henley Beach SA 5022
TELEPHONE: (61 8) 8243 2505
FACSIMILE: (61 8) 8125 5822

TASMANIAN OFFICE:
PO Box 246
Sheffield TAS 7306
TELEPHONE: (61 3) 6491 2529
FACSIMILE: (61 3) 6491 2529

WEBSITE: www.ccaa.com.au

EMAIL: info@ccaa.com.au

Contents

Preface

Cement Concrete & Aggregates Australia (CCAA) developed a research programme in 2004 that examined the use of manufactured sand in portland cement concrete. The research was conducted in two stages:

- Between 2004 and 2006 the physical properties of 21 manufactured sands that are commercially available in Australia were examined. From this work, a specification of properties of manufactured sand was developed and submitted to Standards Australia for inclusion in AS 2758.1 *Concrete Aggregates*. A number of other properties were found to be of use in Quality Control of individual sources but were not considered suitable for the specification of material.

  Refer to the report on the first stage of the research project entitled *Manufactured Sand – National test methods and specification limits*.

- Between 2006 and 2008 a second stage examined eight of the original twenty one samples selected to cover the range of physical properties identified in the first stage of the research project. Each of these samples was tested in a series of mortar trials designed to examine the effects of the manufactured sand on the plastic and hardened properties of the mortar. Mortar tests provide a direct link between the properties of the manufactured sand and the effects on the concrete mix. Attempting to evaluate the effects of manufactured sands using realistic concrete mixes would have introduced other variables such as the effects of the coarse aggregate, supplementary cementitious materials and admixtures into the analysis of the results.

  Refer to the report on the second stage of the research project entitled *Manufactured Sand – Abrasion resistance and effect of manufactured sand on concrete mortar*.

1

Introduction

1.1 SCOPE

This guide is limited to the use of manufactured sands in portland cement concrete. Manufactured sand can be used in asphaltic concretes and might be used in fills, road bases and filter applications but these applications have not been considered. Many of the tests and the specification limits may be relevant to these other applications but this relevance should not be implied from this guide without further investigation.

The testing and research on which this guide is based, targeted the use of manufactured sand in normal purpose concrete. No testing was conducted that allowed for assessment of concrete used in pavements or marine structures or for other special purposes.

This guide is based on the findings of the research and provides the best information currently available in Australia on the successful use of manufactured sands in portland cement concretes. The reports presenting the data and recommendations of the research projects sponsored by CCAA are available on the CCAA website www.ccaa.com.au.

1.2 WHAT IS MANUFACTURED SAND?

When rock is crushed and sized in a quarry the main aim has generally been to produce coarse aggregates and road construction materials meeting certain specifications. Generally, this process has left over a proportion of excess fines of variable properties, generally finer than 5-mm size. The premixed concrete industry has for some time tried to find ways to utilise this material as a controlled replacement of natural sand. In order to do this it has been recognised that provided the material is appropriately processed and selected from suitable materials then a sand replacement can be produced to meet the highest quality concrete specification. Manufactured sand is defined as a purpose-made crushed fine aggregate produced from a suitable source material. Production generally involves crushing, screening and possibly washing. Separation into discrete fractions, recombining and blending may be necessary. It is recognised from both local and overseas experience, that some quarry sources or some rock types within any particular quarry would not be suitable for use as manufactured sand in concrete.

The research conducted has demonstrated that weathered and altered materials will adversely affect water demand in mixes, with predictable effects on mix strength, shrinkage and workability. Properties that are advantageous in crushed fine aggregate for some uses, eg low levels of plasticity for crusher dusts used in road bases, will be disadvantageous in crushed fine aggregate intended for use in concrete. Similarly, the research demonstrated that with suitable mineralogy, manufactured sands with levels of microfines (material less than 75-micron) exceeding 10% can be used in the production of portland cement concrete.

It is clear from the definition for manufactured sand that it was never acceptable for quarries to produce a crusher dust that results from the fine screenings of all quarry crushing and call this material manufactured sand. Particularly for quarries that have different rock types or that have differential weathering or alteration patterns across the extraction area, crushed fine aggregate needs to be produced to specification and controlled by quality programmes. Quarry plant has to be capable of producing different fine crushed product and each of these materials will be handled separately, depending on the raw feed being crushed at any time. This may require separate raw feed stockpiles or separate handling schemes for different quality raw feed. The response of each quarry to the requirements for producing manufactured sand will be unique, but what is emphasised is that manufactured sand is not a general crusher fines under a different marketing label.

Production of manufactured sands on the east coast of Australia over the past decade has usually included processes that have attempted to improve particle shape in the fine aggregate. Beyond this, a number of plants have washed product as a means of controlling the level of microfines in the product and/or as a means of controlling active clays. Some plants have the capability of controlled sizing and blending of raw feed to produce manufactured sands. Each of these process controls represents source-specific responses to producing a product fit for use in concrete. However, none of these processes should be required by specifications for manufactured sand. Rather, performance or property-based specifications will define the requirements of the material, while the production process will be the unique response required to achieve the requirements at any source.

Throughout this guide, the term 'natural sand' is used to identify the material traditionally recovered from geologically recent deposits of sand-sized materials. Typically these deposits are from Quaternary deposits in streams, rivers, estuaries, lakes, lagoons or dunes. For instance the Brisbane market draws from the Morton Bay deposits while Sydney's current sources are from the Kurnell dunes or from flood plain deposits on the Nepean River. Significant differences between natural sands and manufactured sands result from the geological processes of shaping and sorting that has occurred with most natural sands. Thus the individual grains in natural sands tend to be rounded to sub rounded and have a smooth surface texture. If they are more-mature sediments (ie further from the source of erosion) they will tend to be better sorted, to the point with dune sands that they tend to approach single sized materials. Most natural sands have been abraded to the point that weaker minerals (clays and softer altered minerals) have been separated and removed from the deposits. Abrasion can continue to the point that natural sands become mono-mineralic (ie quartz sands) These processes are sufficiently common that they are relied on by the current Australian Standard AS 2758.1 for concrete aggregate (Clause 9.2.1 and notes) to excuse the need for durability testing.

By contrast, crushed fine aggregates typically consist of a graded material, and contain angular particles with a rough surface texture. Unless steps have been taken to control the raw feed to the quarry crushers, crushed fine aggregate contains, or perhaps even concentrates, weak minerals or particles exposed at the quarry faces. Unless the quarry rock is highly friable or is mono-mineral, manufactured sands comprise of broken rock fragments and combined grains rather than a single mineral type.

Some friable sandstones represent a product that cannot be classified on the criteria given. Where sandstones can be ripped easily and with minimum work, are separated into mainly free mineral grains and processes are in place to control the presence of clay cements, then friable sandstones might be considered akin to natural sands. However, where the sandstones are worked by drilling and blasting or require crushing and the crushed product contains a proportion of angular particles or particles consisting of mineral grains and adhering matrix material, then the product is closer to a crushed fine aggregate.

1.3 DIFFERENCE BETWEEN MANUFACTURED SAND AND CRUSHER DUST

Quarry plants vary significantly in their degree of sophistication, in the range and extent of plant process controls and in the degree to which quarry raw feed is controlled to the plant. In simpler plant configurations the quarry raw feed, even when the raw feed is selected on some basis of quality, is processed through two, three or four stages of crushing and shaping and then is separated into a variety of sized aggregates. Usually all aggregate sizes are plus 5 mm and the fines removed at minus 5 mm are stockpiled as crusher dust. More-sophisticated plants will have the capacity to recover and reblend sized aggregates into graded products such as road bases or graded concrete or filter aggregates. Some plants will have the capacity to add stabilising agents, precoating agents or measured water to mixes to meet specific market demands. In rare cases plants will have the capacity to produce multiple products of similar grading but with different rock quality dependent on the source of quarry raw feed.

Most plants however direct the crushed fines to a single dust stockpile. Provided plant settings are not altered to any great extent and the quarry rock types do not vary excessively, the crusher dusts will settle to a relatively consistent product. Variation in the sizing of the product will result from screen and crusher wear, resetting, and the occasional errors such as a broken screen or screen overflow. Product quality will vary dependent on the range and quantity of different rock types within the quarry. For most market requirements these variations are acceptable.

Most crusher dusts of the type described have been used as a blend component in the production of road bases, although some plants produce high quality road bases by crushing quality raw feed into a full crusher run product where the fines are not separated. In road bases, if the crusher dusts contain a quantity of weathered or altered fines that result in low levels of plasticity, this is usually accepted as being advantageous to the performance of the road base. Similarly, crusher dusts have been used as fills under slabs, where their ability to retain form, assisted by low levels of plasticity, enhances their ability to be compacted and yet to be fine enough that the fill pad can be easily trenched for drainage and service lines, making them useful construction products.

From suitable sources, some crusher dusts are used as the fines component in asphaltic concretes. Provided that the dust does not contain mineralogy that is water susceptible, the angular character and rough surface texture of the crusher dusts improve the internal friction of the mix, compared to what might result from the use of natural sands. Crusher dusts used in asphalt are limited by the requirements of the asphalt plants. The dusts cannot have too high a percentage passing the 75-micron sieve because of constraints imposed by the mix designs, and because the asphalt plant drier exhausts carries the dried microfines into the bag house, overloading the filters.

Crusher dusts may be supplied as stabilised product; usually the stabilising agent is cement but some product has been supplied as lime or lime/ fly ash stabilised. Stabilised crusher fill has been successfully used as bedding for pipes and as insulating material around high voltage power lines in addition to more mundane use as a stiffer fill material.

Considering all the current uses for crushed fine aggregate, it is apparent that the range of applications implies a diversity of engineering properties and not all crusher dusts are suitable for the full range of applications. As the performance criteria for the product becomes more critical, so specifications are developed and the basic product tends to diversify.

Manufactured sand is a further development in the use of crushed fine aggregate. The term 'Manufactured Sand' has been developed in world-wide literature to refer to that crushed fine aggregate specifically developed for use as a fine aggregate in concrete. Like any other component of concrete, manufactured sand must be controlled by specification that is suited to the end performance required of the concrete. It is the specification and the process that must be developed at each source to comply with the specification that will distinguish manufactured sand from other products developed from crushed fine aggregate.

1.4 BLENDING WITH NATURAL SANDS

Most sources of manufactured sand supply product directly to premixed plants where it is usually blended with natural sand. Reasons for blending can be summarised as follows:

→ **Natural sands improve workability of fine aggregate**

The better shape and smoother surface texture of most natural sands reduces the inter-particle friction in the fine aggregate component of the concrete mix grading. The consequence is improved workability (usually measured as improved slump) for the same water demand. When blends of manufactured sand and natural sands are measured in the New Zealand Flow Cone test the measure of flow time is reduced, indicative of a material with lower internal friction.

→ **Blending is effective in controlling some adverse properties**

Blending is effective in reducing the level of microfines in the fine aggregate used in the concrete mix compared with the microfines in the manufactured sand. Blending is in fact the simplest and probably the most cost effective means of minimising any adverse properties arising from the typical 10 to 20% passing 75-micron fraction present in most manufactured sands. The microfines are the proportion of the grading most likely to include mineralogy that will increase water demand in the concrete mix. Blending has been shown to reduce and control this trend. In addition, CCAA research has demonstrated that high levels of microfines correlate with lowered bleed. Where this situation is not desirable, blending with natural sand will reduce the microfines in the blended fine aggregate, increasing the bleed.

→ **Ability to supply market demand**

For most quarries supplying crushed aggregate and other rock and blended engineering materials, the bulk of products are produced at 40 mm nominal size or finer. Typically, about 30% of the quarry production output is crushed fines of 5 mm maximum size. A significant proportion of this material is used to supply fines for roads bases, to supply fills and to supply asphalt production. Some fine material is not suitable for use as manufactured sand for concrete, while not all quarries are capable of producing suitable material for manufactured sand.

In areas where manufactured sand is already in significant production it is apparent that most quarries would not be capable of producing sufficient fine material to meet the demand of the premixed concrete market if the total of the fine aggregate in concrete was manufactured sand. Although a few concrete plants do supply mixes where the total of the fine aggregate is manufactured sand, these mixes represent only a small proportion of the total concrete plant output. The common understanding in the industry is that quarries would not be capable of meeting a demand of 100% use of manufactured sand by the premixed concrete industry. Realistic expectations that allow the quarries to meet market demand appear to be around 30 to 50% replacement of natural sand with manufactured sand.

2

Properties of Manufactured Sand

2.1 GEOLOGICAL AND MINERALOGICAL

Manufactured sands are produced from a wide range of rock types. **Table 1** lists the rock types included in the research.

TABLE 1 Rock types included in the research

Rock type	Number of sources
Basalt	3
Granite	3
Latite	2
Limestone/dolomite	2
Meta argillite	1
Meta greywacke	2
Picrite	1
Quartzite	2
Rhyodacitic tuff	1
Rhyolitic tuff/ignimbrite	2
Trachyte	1

Most of the physical properties tested did not appear to be sensitive to rock type but were affected by the mineralogy developed in the rocks by either weathering or alteration. The clear exception was when the samples were tested by the Micro Deval apparatus. In this test the softer limestones had higher losses than most of the siliceous aggregates. This appeared independent of whether the limestone sample was weathered or not. The amount of testing conducted to date is limited but it would be advisable to avoid the use of limestone manufactured sands in circumstances that require high abrasion resistance in concrete.

The mineralogy of manufactured sands is related to the rock types in broadly predictable patterns. Kaolinites are more likely to be found in the acid rock types while the smectities and chlorites are more dominant in the basic rocks. Alteration products in rocks rich in feldspars are dominated by illite or sericite fine micas.

Although it is useful to identify the mineralogy of the manufactured sands, the CCAA research did not find any direct linkage between the mineral types present and the effects on physical properties or mix properties. Rather, the relationship is between the activity of minerals present and their quantity in the manufactured sand or mortar mix. Thus, small quantities of the expansive smectite clays can be tolerated while the poorest performing samples of the research were an altered quartzite and a limestone/dolomite that were both rich in sericite.

The best predictor of the effects of mineralogy on the acceptance and performance of the manufactured sands and on the properties of mortar mixes was the Methylene Blue absorption value (MBV) multiplied by the percentage of fines passing the 75-micron particle size. The methylene blue dye is preferentially and proportionately absorbed by layered silicates (clays and micas) that are hydrophilic to a greater or lesser degree. As opposed to X-ray analysis, which can provide both identification and some quantitative analysis of individual minerals present in the sample, the MBV provides a standardised indicator of the total activity of all active materials in the sample. This means that comparing MBV results allows a comparison between the relative reactivity between samples, but until the quantity of reactive material is determined, the MBV does not provide by itself any indication of the consequent effects of the mineralogy on concrete mixes.

Water demand of mixes correlated with increases in reactive mineralogy measured by the multiple of MBV x passing 75-micron. The research did not indicate any findings different from that common in the literature; smectite clays were more reactive than kaolinite with chlorites falling somewhat in between. However, in the mortar trials conducted, the greatest overall reaction came from samples with high levels of passing 75-micron material that was dominated by sericite. Loosely, material identified as sericite may involve compositions ranging from muscovite (mica) through to a final altered form of illite or hydromuscovite. All forms of these micaceous minerals have the potential to bind water in their structure. Microcrystalline forms of illite and sericite, in particular, have a highly reactive surface compared to their mass.

2.2 PHYSICAL

The voids content of the aggregate or its inverse in some design methods (the packing density of the aggregate) is directly correlated with the water demand of concrete mixes. Higher voids resulting from aggregate gradings, particle shape or surface textures require that paste fill the voids in the aggregate skeleton before concrete will act as a plastic material for placement.

The introduction of manufactured sand into concrete mixes, results in particle size distributions that in most cases are close to graded materials that would tend to minimise voids. However, the angular nature of the material and the rough surface texture tend to increase voids in the sand. Higher level of fines in manufactured sand results in a higher specific surface area that usually increases the water demand of the concrete. On the other hand, the microfines from the manufactured sand 'bulks' the mix paste volume, thus avoiding additional cementitious material. The physical properties of manufactured sands (particularly in mixes where the quantity of manufactured sand is greater than 50%) will have a significant impact on concrete mix properties; this impact cannot be easily modelled by comparison with natural sands. There are sufficient differences between natural sands and manufactured sands, that even where the particle size distributions of the materials are similar, mix characteristics will vary significantly.

The New Zealand Flow Cone test (NZS 3111, Section 19) is one procedure that attempts to examine the interaction between the size distribution, particle shape and surface texture of manufactured sands. The test demonstrated the change in void content of the aggregate as a single-sized sand was blended with the manufactured sands. The measured voids content could be correlated with changes in water demand of the mortar mixes. Workability perceptions had some correspondence with the measure of flow time in the test, perhaps indicating that the flow time provides an indication of the shape and surface texture of the sand.

Durability of manufactured sands, as for coarse aggregates, needs to address properties of hardness, strength, toughness and the ability to withstand abrasion. Although the fine aggregate will not tend to carry load in the concrete structure to the same extent as the coarse aggregate, the fine aggregate must be sufficiently durable that it will not fret or break away at the concrete surface, nor should the particles be soft enough that they can be abraded under the wear expected on the surface.

The current Australian standard for concrete aggregate does not address the durability of fine aggregate. The only test procedure that can be applied to fine aggregate is the Sodium Sulfate loss; the specification limits for this test are set so high that virtually no materials would be rejected. The Australian Standard currently relies on the supposition that natural processes have removed weak and altered material from sand deposits and that material recovered from natural deposits is, by its nature, sound and durable.

Manufactured sands are tested for durability using either the Sand Equivalent test (AS 1289.3.7.1), the Degradation Factor Fine Aggregate (AS 1141.25.3), or the Sodium Sulfate loss (AS 1141.24). Each of these tests was found to have a partial correlation with the Methylene Blue Value, suggesting that each test measures the altered and clay minerals present. The Sand Equivalent measures clay in the microfines of the aggregate grading while the Degradation Factor and the Sodium Sulfate are affected by minerals within the broken rock particles in the coarser portion of a manufactured sand grading, the finer fractions having been rejected by the test procedure. On this basis, Sodium Sulfate and Degradation Factor may be more appropriate for testing washed sands while the sand equivalent is better suited for unwashed materials.

The specification proposed for inclusion in AS 2758.1 includes lower acceptance criteria for the Sodium Sulfate loss than the current limit.

None of the durability tests mentioned are suitable for measuring 'hardness' or 'toughness' in manufactured sands; for this purpose the Micro Deval procedure is recommended. There is only a limited number of test machines currently in Australia and work in assessing the test procedure has only commenced. However, the test can be run on fine aggregate and it appears capable of distinguishing between 'soft' and 'hard' rock, as opposed to ‘altered' and 'weathered' mineralogy that tends to be the criteria of the other durability tests. It is hoped that the apparatus will allow for the assessment of abrasion resistance, particularly for manufactured sands that might be used in concrete pavements.

2.3 TEST METHODS SUITABLE FOR MANUFACTURED SAND

General This section of the guide recommends the test procedures found to be useful for evaluating and controlling manufactured sands. It suggests how the tests might be used and recommends a basic testing frequency for use when no other testing frequency is required by specification, contract or circumstance. All testing frequencies are ideally set by the variability of the product, the level of certainty required in the results, the quantity of the product under test and the uncertainty of the test procedure. Where these factors are not known, as in this case, the best that can be offered is an opinion based on experience of the variability of similar products.

Grading and passing 75-micron

Particle size analysis (grading) conducted to AS 1141.11 on manufactured sands, down to the 75-micron size fraction, is useful as a means of determining the impact the sand has on the total combined particle distribution and hence an indicator of particle packing or voids within a concrete mix. From this perspective, grading is considered a reportable test, and would be specified in a supply agreement for any particular source. In assessing manufactured sand, the grading is a necessary test for assisting in design and quality control of concrete. However, CCAA research concluded that the range of gradings that were capable of use in concrete was so broad that it was not feasible to specify an ideal grading in a National Specification that did not result in the acceptable grading envelope being so broad that any semblance of control was lost.

Control of grading variation is important for specifiers to develop confidence in the predictability of the engineering properties of manufactured sand and hence to maintain control of a concrete mix. Nominated grading with tolerances is the most practical arrangement for specifier and supplier and this is the approach that has been suggested in the specification for manufactured sand that follows. This approach has been recommended to the National Specification for concrete aggregates. Individual contracts will have to deal with methods of enforcing this specification and in determining what action needs to be taken to correct mix properties if sand gradings vary from design.

Manufactured sand must meet a broad envelope of grading in order to be defined as sand (as opposed to a coarse aggregate). CCAA recommends that a top, mid and bottom sieve are used to ensure that the manufactured sand is actually a fine aggregate and is usable alone or in conjunction with other fine materials *(see Specification)*.

Successful manufactured sands are generally 4 mm minus or smaller. This is reflected in samples of manufactured sand already in production in Australia and tested in CCAA research. All but one sample ranged from 95 to 100% passing the 4.75-mm sieve. An excess of material retained on the 4.75-mm sieve is regularly reported to have a negative impact on concrete slab finishing processes, as well as reducing concrete workability.

IN SUMMARY:

- → Gradings are a part of the investigation process for manufactured sand. Compliance with a nominated grading and variation limits will be a part of most supply agreements. Gradings will be a part of Quality Control measures at plants producing manufactured sands.
- → Washed gradings would be performed at least weekly at plants with low production rates and more frequently on major production plants.

Deleterious fines

This guide recommends that deleterious fines are best controlled by testing the manufactured sand by washed grading in accordance with AS 1141.11. The MBV of the manufactured sand is evaluated by the International Spray Seal Association's procedure given in Bulletin 145. Manufactured sand is considered suitable for use in concrete if the multiple of the MBV and the passing 75-micron size of the sample is 150 or less.

However, the value of the multiple (MBV x passing 75-micron) for the fine aggregate used in concrete should be maintained at a value of 100 or less, this means that any manufactured sand with a value greater than 100 must be used in a blend with another manufactured sand or a natural sand so that the combination of materials conforms to the 100 limit. As these blends are usually produced at the premix plant, some responsibility for the control of the blend must rest with the premix producer.

Deleterious fines may be controlled using the Sand Equivalent (AS 1289.3.7.1) procedure. Limited testing using this procedure was undertaken in the CCAA research and a control value of minimum 60 was suggested as suitable.

IN SUMMARY:

- Either the MBV or the Sand Equivalent test could be used in the investigation of potential source for manufactured sands. Both tests have been recommended for inclusion in AS 2758.1 for the specification of manufactured sands. One or other should be chosen as a Quality Control test for any plant producing manufactured sand.
- Plant production of manufactured sand should be tested for MBV or Sand Equivalent at least monthly or at any time that there is reason to believe that the amount or type of clay or active mineral component in the source fines might have changed.
- Premixed concrete producers can evaluate the level of deleterious fines in their blend by proportioning the values provided by sand producers or by testing a sample of the fine aggregate blend. Premixed concrete producers are responsible for the accuracy of the blend proportioning. Clearly, Sand Equivalent data from one sand supplier cannot be proportioned with MBV data from a different supplier.

Shape and surface texture

Shape and surface texture are measured indirectly by the Flow Cone (NZS 3111) procedure. However, as changes in grading will also influence the Flow Cone it is not practical to design a test specification that could be used over a range of products.
The acceptance envelope provided in the chart included in the procedure was designed for natural sands or blends of natural sands. Its application to manufactured sand and sand blends appears appropriate but has not been researched.

The Flow Cone is best used as a design procedure to help determine suitable 'workability' in fine aggregate blends. The test might also be used as a Quality Control procedure on specific sources where changes in results would indicate possible changes in crushing characteristics

IN SUMMARY:

- The test will probably be used only for blend design. If it were to be used for quality control at a plant an appropriate frequency of testing would need to be established dependent on the sensitivity of the test to detect changes in sand production and the potential effect of those changes on the properties of the concrete mix.

Durability tests

Durability tests for manufactured sands include the Sodium Sulfate Loss (AS 1141.24) and Degradation Factor (fines) (AS1141.25.3). In the CCAA research, the Sand Equivalent test was considered as a durability test but following analysis of research results, the test is now better considered as a test for deleterious fines.

Both the Sodium Sulfate and Degradation Factor are limited in that they test only a portion of the sand grading and may therefore be limited as product control tests unless combined with a measure that evaluates deleterious fines. The Sodium Sulfate test is plagued by lack of reproducibility and appeared to have specification values set too high. It is recommended that a loss value for Sodium Sulfate of 6% maximum to be specified (as opposed to a value of 15% loss in the current Australian Standard).

The Degradation Factor (fines) is considered a source-rock test and may need to be combined with a control measure for deleterious fines. Where used, the suggested specification is minimum 60. The test may not evaluate particle strength and may need to be combined eventually with a measure such as the Micro Deval.

Neither of the current durability tests evaluates the strength or resistance to abrasion of the particles in manufactured sand. For this reason CCAA has commenced research into the Micro Deval procedure in the belief that it may eventually prove a useful fine-aggregate durability test.

IN SUMMARY:

- The variety of durability tests might be useful in the evaluation of a potential source of manufactured sand. Other than that, the tests will probably be used as specification compliance checks at irregular intervals.
- Testing frequency is suggested at once each six months.

Mortar trials

Potential manufactured sand sources and the possible blends of the manufactured sand with available natural sands are evaluated rapidly by using a structured series of mortar trials. These trials provide useful information on the probable effects of the manufactured sand on the properties of the concrete without the variables of aggregate performance, admixtures or supplementary cementitious materials having to be considered at the design stage. Once a suitable blend of the manufactured sand with natural sand has been determined, the selected blend can be confirmed in full-scale mix design tests.

A suitable procedure for mortar trials is appended to the CCAA research report for mortar trials of eight manufactured sand samples. The procedure is designed to provide data on the water demand, strength and shrinkage of manufactured sands and blends.

IN SUMMARY:

- The procedure would be used as part of the investigation stage for manufactured sands or might be used by a concrete producer as part of an evaluation programme of a sand source.
- The procedure may be repeated by a concrete producer on an annual basis as part of a mix or supply confirmation process.

2.4 EFFECTS OF MANUFACTURED SAND ON THE PROPERTIES OF CONCRETE

Water demand in mixes using manufactured sand appears, from the research, to be controlled by two main factors. For mixes where the mineralogy of the microfines was either inert or had been so diluted that its influence was minimal, then water demand was strongly influenced by the voids in the sand. In turn, voids in the sand are a consequence of the interaction between the grading of the sand and the particle shape and surface texture of sand. Thus, mixes could be high in voids when they consisted of predominantly rounded, smooth but single sized sand. But high voids content is equally associated with well graded sand that is angular with a rough surface texture.

For mixes where the manufactured sand forms a significant proportion of the total of fine aggregate in a mix, there is a definite correlation between water demand and the activity of the microfines measured by the multiple of the MBV and the passing 75-micron value. Water demand increases with the increasing quantity of active minerals in the manufactured sand; the CCAA research has indicated when these effects are taken into account, that once the multiple of the MBV and the passing 75-micron for the total fine aggregate exceeds 100, the effects on water demand and the consequent effects on mortar shrinkage and strength, cease to be acceptable. This limit is likely to apply whether the fine aggregate is a blend of manufactured sand and natural sand or is totally composed of manufactured sand.

Mortar trials conducted on a series of blends of manufactured sands with natural sands demonstrated that the strength of the mortar was directly related to the water demand of the mix. This relationship was almost independent of whether the water demand was the result of increased voids in the mix or the result of increased activity of the microfines, caused by either an increase in the amount of material passing 75-micron, or an increase in the MBV.

Likewise, the shrinkage of mortars was for the most part predictable and related to the water demand of the mix. However, a few trials resulted in shrinkage that was beyond that suggested by the water demand of the mix. These trials all involved manufactured sand of high microfines and it is probable that the additional drying shrinkage is the result of drying and consequent shrinkage of active mineralogy. This shrinkage is additional to the drying shrinkage of hydrated cementitious products that are predicable from the water demand. This effect is best controlled by specifying a limit on the level of active microfines that can be accommodated in a mix.

Increased perceptions of difficulty with workability appear to be associated with the angular nature of the particles in manufactured sand and with the surface roughness of the particles. These perceptions were recorded whether there was coarse (5-mm) particles in the top end of the manufactured sand grading or not. Even manufactured sands that were all passing 2.36 mm in size were still perceived as 'gritty' to finish.

Mix workability improved as the manufactured sand was blended with natural sand. This may be the result of using a proportion of better shaped sand with a smooth surface texture, while in some cases it may have been the result of higher water contents.

3

Specification for manufactured sand as concrete fine aggregate

SCOPE

This specification defines the acceptance criteria for manufactured sands supplied for use in the fine aggregate of concrete. The manufactured sand may be one component of a fine aggregate blend, or it may comprise the total fine aggregate for the mix. This specification defines properties determined from manufactured sands that have been used successfully in fine aggregate. However, it provides no guidance on the extent of the addition of the manufactured sand. A material complying with this specification will be acceptable for blending, but the blend proportions must be determined by trials. The effects of complying manufactured sand on the water demand, plastic or hardened properties of concrete are not readily predicted and are not addressed by this specification.

DEFINITIONS

Manufactured sand: A purpose-made crushed fine aggregate produced from a suitable source material and designed for use in concrete or for other specific products. Only source materials with suitable strength, durability and shape characteristics should be used. Production generally involves crushing, screening and possibly washing. Separation into discrete fractions, recombining and blending may be necessary.

Sound, durable stone or source: For the purposes of this specification sound and durable stone or a sound and durable source shall mean source rock or stone that can be shown to comply with the durability clause (Clause 9) of AS 2758.1 for exposure classification B1 or B2.

GENERAL

Manufactured sand shall be produced by crushing and screening sound and durable source rock. Crushing shall include processes to improve the particle shape of the manufactured sand. Production processes shall ensure that sand stockpiles are not contaminated with weathered or highly altered rock or with clay or other contaminants. Crushing of multiple-source rocks into a single sand stockpile shall not be permitted unless it can be demonstrated that such a process is under blend control and produces a consistent product. In accordance with Clause 13 of AS 2758.1, volcanic breccia, mudstones, shales and highly weathered or altered rocks shall not be used as source rock for manufactured sand.

SAMPLING

The sampling of aggregate and of source rock shall be carried out in accordance with the methods described in AS 1141.3.1 and AS 1141.3.2 respectively.

> *Note:* *Unless otherwise stated in this specification, the frequency of testing should be agreed and specified in the supply contract between the producer of the manufactured sand and the concrete producer.*

TESTING

Testing shall be conducted in accordance with the methods specified in this specification. Proportions, ratios and percentages are expressed in relation to units described in the test methods and are specified in comparable units in this specification.

DENSITY AND WATER ABSORPTION

When determined in accordance with AS 1141.5, the particle density of manufactured sand, expressed as the saturated, surface dry value, shall not exceed 3.2 t/m^3 and shall not be less than 2.1 t/m^3.

PARTICLE SIZE DISTRIBUTION

Because of the wide variation in crushing characteristics of natural materials, and significant variation in the design of crushing plant, it is not practical to define an overall grading specification for manufactured sands. Instead, the grading of individual components of a fine aggregate shall be determined by the concrete manufacturer and the variation of the individual gradings shall be controlled by the producer of the component, whether natural or manufactured sand.

The producer of manufactured sand shall provide a history of grading results to indicate the average grading and variation of the manufactured sand proposed for supply. In addition, the producer shall nominate a grading envelope for the product that will be supplied to the current contract which shall be known as the 'submitted grading'. Nevertheless, manufactured sand, by definition, shall conform to the general grading limits given in **Table 2**. Consideration may be given to manufactured sands with greater than 20% passing the 75-micron fraction provided they are used in combination with another sand where the total % passing 75-micron for the combination does not exceed 15% and provided they meet the limits of deviation in every respect.

The 'limits of deviation' (see **Table 3**) are the maximum variations in percentage units between the submitted grading and any particular test result during the course of the contract.

> Notes: *Reasonably consistent grading is necessary for aggregate supplied under any one contract to ensure practical control of concrete manufacture.*
>
> *It is recognised that smaller deviation values than those specified in Table 3 may be more appropriate to particular projects. Where smaller deviations are required, values should be nominated in the works specification.*

TABLE 2 General grading limits

Sieve size (mm)	**Cumulative amount passing** (%)
4.75	90 to 100
0.6	15 to 80
0.075	0 to 20

The producer of manufactured sand shall review the current 'submitted grading' and shall advise all customers whenever a grading result departs from the submitted grading by more than the deviation limits given in **Table 3** at any sieve size.

TABLE 3 Grading variation limits

Sieve size (mm)	**Maximum deviation** (%)
9.5	–
4.75	±5
2.36	±10
1.18	±15
0.60	±15
0.30	±10
0.15	±5
0.075	±3

PARTICLE SHAPE

If the shape of particles in manufactured sand is to be specified, the test procedures and the applicable limits shall be detailed in the supply specification.

DELETERIOUS FINES

Manufactured sand may be tested for the presence of unacceptable quantities of deleterious fines by either of the following two procedures.

→ Procedure 1

When tested for Methylene Blue Value (MBV) by the procedure of the International Slurry Seal Association (ISSA) Bulletin 145, the multiple of the MBV and the passing 75-micron value of any sample shall not exceed 150.

> Notes: *The effect of fines on the mix properties of concrete depends on the quantity of fines present in the aggregate grading, and the cation exchange capacity of the fines.*
>
> *Manufactured sands with higher measured activities have been used successfully but generally at low addition rates. Sands with multiples to 200 may be used if there is mix design data to demonstrate acceptable concrete performance. Sands with multiples over 200 are unlikely to produce acceptable concrete.*

→ Procedure 2

The Sand Equivalent of a manufactured sand, when determined in accordance with AS 1289.3.7.1 shall be equal to or greater than 60.

> Note: *Where the Sand Equivalent is less than 60, it may still be possible to use the manufactured sand in low blend ratios if the sand is blended with a clean natural sand. In this case, it would be appropriate to apply the specification limit of 60 to the total fine aggregate blend rather than to the manufactured sand component. However,*

the concrete manufacturing process must be capable of accurate and consistent blending if the specification is applied to the fine aggregate blend rather than the individual components.

DURABILITY

General Aggregate durability limits are given in Procedure 3 or Procedure 4; ideally, only one procedure should be used to avoid conflicting interpretations. Unlike the specification for coarse aggregates in AS 2758.1, manufactured sands have been specified to a single limit for all concrete exposure classifications.

→ **Procedure 3**

The sodium sulfate loss for manufactured sand when assessed in accordance with AS 1141.24 shall not exceed a weighted average loss of 6% for all concrete exposure classifications.

→ **Procedure 4**

The Degradation Factor (fines) for manufactured sand, when assessed in accordance with AS 1141.25.3 shall not be less than 60 for all concrete exposure classifications.

ALKALI–REACTIVE MATERIALS

General Fine aggregate combinations intended for use in concrete that will be subjected to frequent wetting, extended exposure to humid atmosphere, or contact with moist ground, shall not react with alkalis in the concrete to an extent that may result in excessive expansion.

Requirements The producer of manufactured sand shall provide appropriate documentation to the concrete producer to allow assessment of the potential reactivity of the aggregate.

Note: *Guidance on assessment and mix design is given in SA HB79.*

IMPURITIES

Sugar When tested in accordance with AS 1141.35, the aggregate shall test negative to the presence of sugar.

Soluble salts

Note: *Excessive quantities of some soluble salts may cause efflorescence on the concrete, corrosion of the reinforcing steel or disintegration of the mass of the concrete. Permissible levels of soluble salts are generally expressed as the proportion of the relevant ion present in the concrete by mass of concrete or by mass of portland cement.*

Chlorides The chloride ion content of manufactured sand shall be determined quantitatively in accordance with AS 1012.20 and shall be reported.

Note: *Water-soluble chlorides in aggregates are more relevant to the corrosion of the reinforcement. Work is currently being undertaken to establish a water soluble chloride test for inclusion in Australian Standards.*

Sulfates The sulfate ion content of manufactured sand shall be determined quantitatively in accordance with AS 1012.20 and reported.

Other salts Manufactured sands that contain other strongly ionized salts, such as nitrates, shall not be used unless it can be shown that they do not adversely affect concrete durability. Restrictions on the presence of these salts may be specified in the project specification.

PERFORMANCE CRITERIA FOR A FINE AGGREGATE BLEND INCLUDING MANUFACTURED SAND FOR USE IN CONCRETE

CCAA research included a series of mortar trials of manufactured sand that, although limited in extent, pointed to performance criteria that should be met by the fine aggregate to be used in the concrete mix rather than by any particular component of the fine aggregate.

One of the objectives of the research was to develop a suitable specification for manufactured sand for use by aggregate producers who are members of the organisation and to encourage authorities and Standards Australia to make use of the specification developed.The specification developed is suitable for the supplier of manufactured sand to a concrete premix plant. It assumes, and states under *Scope,* that the use of any manufactured sand in concrete would be confirmed with mix design trials as there is no guarantee that manufactured sand complying with the specification could be used in concrete in all possible combinations. In fact, the mortar trials demonstrated that some complying manufactured sands needed to be diluted in blends with natural sands before their use would make suitable concrete.

ASTM C33 has attempted to write a specification that considers the total fine aggregate. However, this approach introduces difficulties in enforcing the specification if different components of the combined fine aggregate are drawn from different suppliers. Clearly, changes in supply from more than one supplier may result in the combined fine aggregate failing to comply with a combined specification. But the concrete producer, who may be responsible for enforcing the specification, is also responsible for processing individual components to produce a combined fine aggregate, and is therefore in part responsible for the compliance of the combined properties of the fine aggregate blend.

This document prefers an approach that identifies desirable combined fine aggregate properties, and provides this information as advice to the concrete producer. This advice identifies what might be desirable in the combined fine aggregate, but again the properties need to be confirmed in mix trials. It then becomes the concrete producer's responsibility as to how these trialled combined properties are achieved at the premix plant.

This guide (and, it is expected, AS 2758.1) avoids providing a specification for a combined aggregate grading because such a wide range of gradings is possible that it becomes difficult to restrict the specified grading to the point that it is useful as a control measure. Nonetheless, a reasonable grading that reduces voids in the mix is a useful design criterion, for this reason, the ASTM C33 envelope for manufactured sand blends is reproduced for information in **Table 4**.

TABLE 4 Grading envelope recommended in ASTM C33*

Sieve size (mm)	**Percent passing**
9.5	100
4.75	80 to 100
2.36	60 to 100
1.18	40 to 85
0.6	20 to 60
0.3	10 to 45
0.15	0 to 30
0.075	0 to 15

**The ASTM C33 table may be used only as a guide to the likely suitable ranges of particle size distribution that will normally work in a concrete mix but should not be used as a mandatory specification as alternative particle size distributions to those represented in this table have proven to be satisfactory in concrete.*

In using this suggested envelope, sand gradings that are at the fine limit of the envelope on one sieve and at the coarse limit on the following sieve will cause higher voids in the aggregate. Similarly, sands that are fine and then coarse will also have high voids.

The specification for manufactured sand as a component of the fine aggregate recommends that active mineralogy in the product microfines is controlled by limiting the multiple of the passing 75-micon size and the MBV to a value of 150, with an allowance that values up to 200 may be accepted if additional design testing has demonstrated that material of this quality can be tolerated in the concrete. These limits assumed that the manufactured sand would be a component of a blend and that the natural sand would dilute the effects of active minerals in the manufactured sand.

The possibility of mixes where the manufactured sand represents the total fine aggregate was investigated in the mortar trials conducted by CCAA. The trials suggested that whether as manufactured sand alone, or when the manufactured sand was combined in a blend, the multiple of the MBV for the total fine aggregate in a concrete mix, multiplied by the passing 75-micron for the total fine aggregate should not exceed 100.

THE USE OF MANUFACTURED SAND IN SPECIAL-PURPOSE CONCRETE

As stated under *Scope*, this guide has attempted to address only the use of manufactured sands in portland cement concrete in normal applications. These applications would include normal structural grade concretes up to 60 MPa strength, footings and foundations in non-reactive ground conditions, and some shotcrete applications.

The research conducted to date did not investigate the special properties of manufactured sands required for mortar and concrete used in special applications. There is therefore insufficient information currently available on the potential effects of manufactured sand on concrete applications where performance may be affected by these properties.

Part of the research conducted to date was limited work on the use of the Micro Deval apparatus to evaluate the abrasion resistance of manufactured sands. Some preliminary data has identified the expected lower abrasion resistance of limestone manufactured sands and has provided results where samples of weathered and altered materials were tested. Some overseas specifications provide suggested limits for Micro Deval to correlate with acceptable wear performance but most of these specifications are related to traffic wear on asphalt pavements.

It may be expected that poor abrasion resistance of sands would contribute to poor wear characteristics in concrete flatwork subjected to continual wear such as in heavily trafficked warehouse floors and concrete highway pavements. Future research is required to establish appropriate measures for assessing abrasion resistance of concrete flatwork using accelerated test procedures. Realistic performance criteria need to be established for the structures, and these criteria need to be correlated with the Micro Deval or some other measure of manufactured sand abrasion resistance.

Also affecting concrete pavements is the matter of the polishing resistance of manufactured sands. It is commonly accepted that in asphaltic pavements, fine-grained rocks that are low in free quartz will be prone to polishing under the action of traffic. Although it may follow logically, no similar relationship has been established for crushed fine aggregate. There is no established test for accelerated polishing of fine aggregate, nor has it been established if polishing or polishing resistance in concrete roads is the result of exposed fine aggregate in the mortar or the result of the remaining concrete pavement texture at any point of time. If pavement texture is a significant parameter in polishing resistance, then the matter of suitable assessment of abrasion resistance of the mortar forming the pavement texture is an additional research requirement for polishing resistance.

The performance of marine concretes and concretes in reactive soils is affected by the sorptivity and permeability of the concrete. This in turn is influenced by the void content, air entraining and capillarity of the pores formed in the hardened concrete. The use of manufactured sand in concretes will influence void formation and the probable increase in microfines, particularly if there is active mineralogy, has the potential to alter mix capillarity. It is not anticipated that resolution of this issue will be as involved as that dealing with abrasion and polishing resistance. Adequate test procedures and performance correlations already exist to evaluate potential changes to concrete performance that might result from the use of manufactured sand. However, at this time the necessary data is not available for consideration by this guide. Any proposed use of manufactured sand in marine concretes or in concretes in reactive soils should be assessed appropriately on a case-by-case basis.