Report

Cement Concrete & Aggregates Australia

Research Report

MANUFACTURED SAND

Abrasion resistance and effect of manufactured sand on concrete mortar

November 2008

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

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Cement Concrete & Aggregates Australia

Technical Liaison Committee

ACKNOWLEDGEMENT

The contribution made by members of the Manufactured Sand Subcommittee in initiating, planning, designing and steering the research project to achieve its objectives is acknowledged. The subcommittee comprised the following members:

Mr Tony Thomas *(Chairman)*	Boral Construction Materials
Mr Ion Dumitru	Boral Construction materials
Mr Michael van Koeverden	Hanson Construction Materials
Mr Geoff West	Rocla Quarry Products
Mr Gary Basford	Cemex
Mr Gary Lucas	Cemex
Mr Wayne James	Cemex
Mr Tom Kovacs	Barro Group
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Preface

Cement Concrete & Aggregates Australia (CCAA) through its Manufactured Sand Subcommittee commenced research in 2004 to support the specification and use of manufactured sands. The first stage examined the physical and mineralogical properties of 21 samples of manufactured sand currently in production on the east coast of Australia. The samples chosen represented a range of rock types, company sources and locations. All were being successfully supplied in blends to the market. The purpose of the first stage was to determine suitable specification tests and specification limits for the supply of manufactured sand. It was the intention of the research to prepare a submission to Standards Australia for a redraft of AS 2758.1 to include manufactured sand.

The results of the first stage of the project were published in January 2007 in CCAA's Research Report *Manufactured Sand – National test methods and specification values*. The report recommended that the LCPC packing density test and the Micro Deval test be investigated further and that the effects of the physical properties of manufactured sand on concrete mortar be investigated. This second stage of CCAA research into the use of Manufactured sand addresses these two recommendations. The first section of this report details the supplementary research into the Micro Deval and the LCPC packing density tests. The second part of this report covers mortar trials on eight of the original twenty one manufactured sand samples.

1 Micro Deval and LCPC Packing Density

1.1 INTRODUCTION

Two questions that remained unresolved by the first stage of the CCAA research became the basis of the first part of this stage of the research project.

The first stage identified that the determination of 'durability' in manufactured sand is limited to tests predominantly influenced by the presence of reactive clays in the rock fabric or in the fine crushed tail of the manufactured sand. Of the common tests used in Australia, none measures the rock strength of fine aggregate particles. The CCAA Research Report recommended that the Micro Deval test, used in the USA, Canada, and Europe (especially France) be investigated as a measure of 'rock strength' or 'abrasion resistance' for manufactured sand. There is some possibility that Micro Deval may be useful in satisfying the NSW Roads and Traffic Authority (RTA) in their search for a test procedure that would specify level of abrasion resistance for the mortars that form the texturing on concrete roads.

The second question concerned the use of the LCPC packing density test. The first stage developed test data for packing density for use in the 'BetonLab' design method and it was intended that this design method would be used as part on the second stage testing manufactured sand mortar trials. The packing density test procedure is described in *Laboratoire Central des Ponts et Chaussees (LCPC)* test method 61 and was used in the first stage to test all 21 samples.

As the test is rarely used in Australia, there is little information available to confirm the validity of the test data generated in the first stage. CCAA adopted a recommendation to use this supplementary project to confirm data developed by Hanson's laboratory in the first stage and to investigate the usefulness of the test for manufactured sands in Australia.

The design of the first stage project allowed for the retention of sufficient material from each source sample to allow for additional research. For this second stage, eight samples were selected from the original twenty-one, based on the physical properties reported in the first stage. At the time of the selection, the research committee did not know the source location or the rock type of the selected samples.

This report of research funded by CCAA covers testing work undertaken at Hanson's laboratory at Wallgrove NSW and at Cemex's laboratory at Northmead NSW between November 2006 and July 2007. The report includes:

- a description of each test and a discussion of its relevance to manufactured sands;
- an analysis of the specific test results from this programme and the relationship of the results to current standard specification limits (if known) for the method;
- a discussion as to whether the test method should stand alone or be reported and reviewed in conjunction with the results from other test methods;
- a discussion and recommendation as to whether the test method should be a source quality measure only (ie mainly used for monitoring the variability of a single source) or if it may be used for setting specification values used for control of many sources;
- recommendations regarding specification and/or variability limits.

1.2 OBJECTIVES

This part of the research project had the following objectives:

1. To determine the suitability of the Micro Deval procedure as a specification test for manufactured sand
2. To examine the use of the Micro Deval as a means of controlling abrasion of texturing in concrete pavements
3. To confirm the LCPC packing density test data from the first stage of the research
4. To commence collection of 'repeatability' and 'reproducibility' (precision) data for the LCPC packing density test.

1.3 METHODOLOGY

A set of eight samples was selected from the original 21 samples tested in the first stage. The first stage had demonstrated the use of a multiple of the MBV and passing 75 micron results as a measure of the activity of the microfines (passing 75 micron material) in the manufactured sand. The set of eight samples was selected as four pairs of samples, each member of the pair with matching properties but with an increase in the MBV x 75 micron value between the pairs. The same eight samples were selected for the mortar investigation, where the effect of this increase in activity on concrete mortars would be assessed. **Table 1.1** shows the variation in physical properties of the eight samples.

In addition, a sample of blended Sydney sands, typical of the fine aggregate blend used in Sydney ready mixed concrete, was included as a control. The blend consisted of 80% coarse Nepean River sand and 20% Kurnell dune sand.

Hanson's laboratory split each of the nine samples (eight from **Table 1.1** plus the control) into four test portions. Hanson and Cemex used one portion each for LCPC packing density testing and Hanson used another portion for Micro Deval testing.

Both laboratories prepared the test portions for the LCPC packing density by removing the passing 75 micron fraction from the test portion before completing the test. The project instructions had intended that following the original testing, the tested fractions would be retained and the test would be repeated using the same equipment but employing a different laboratory technician. This process is accepted by ASTM as a means of assessing repeatability. Hanson's laboratory completed this process but the results indicated that the initial testing had altered the test fraction. Cemex laboratory did not undertake the duplicate tests.

Hanson laboratory prepared a third set of test portions in accordance with the requirements of test method A23.2-23A, the Canadian Standards *Test Method for the Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus.* After the preparation, Hanson laboratory conducted and reported the test results for the eight selected samples and the control sample.

TABLE 1.1 Physical properties of selected manufactured sand samples

	SIZING TEST RESULTS			FLOW CONE RESULTS		DURABILITY RESULTS				CALCULATIONS	
SAMPLE	**Mass passing 75 µm** (%)	**Mass less than 2 µm** (%)	**Clay and silt AS 1141.33**	**Voids** (%)	**Flow time** (secs)	**MBV**	**Sodium sulphate loss** (%)	**Degradation factor** (fines)	**Sand equivalent**	**Ratio clay and fine silt to % passing 75 µm**	**MBV x % passing 75 µm**
D69	9.0	1.6	13.0	42.8	28.5	3.4	0.4	85.0	74.0	1.4	30.0
S51	8.0	0.5	13.0	41.3	27.9	1.2	0.2	89.0	81.0	1.6	8.0
L16	10.0	2.0	22.0	42.3	26.6	10.8	1.4	88.0	88.0	2.2	108.0
N53	11.0	1.8	22.0	43.2	31.2	12.0	0.7	90.0	90.0	2.0	121.0
G80	12.0	2.4	31.0	42.1	35.6	11.8	0.7	86.0	66.0	2.6	141.6
L24	17.0	0.9	33.0	37.1	31.8	11.4	1.1	84.0	60.0	1.9	193.8
S68	23.0	4.6	48.0	45.6	36.1	14.3	1.3	74.0	40.0	2.1	322.0
T68	19.0	4.5	Indeterminate	41.4	25.2	24.2	6.0	53.0	25.0	—	456.0

1.4 PROJECT SAMPLES

As stated, the samples used in this stage were a subset of the samples used in the first stage of the CCAA research project on manufactured sand. A report of that first project has been published and the data given in **Table 1.2** extracted from that report. Sample identification is unchanged from the first stage. In order to explain the results of the Micro Deval test, the rock type for each source had to be identified even though this information was not available at the time the samples were selected. This information has been included in **Table 1.2** along with comparable data on the sands blended to produce the control sample.

TABLE 1.2 Typical use of manufactured sand

Sample code	**Material used singularly as sand** (YES/NO)	**Material used as a proportion of sand**		**Other comment**
		Typical proportion/ content	Maximum limit (if any)	
D69	NO	40%	100% (in special applications)	Max % market driven – dependant on customer, workability and finishing requirements. In winter, use of a higher proportion manufactured sand may be possible. Rhyodacitic tuff
G80	YES	100%	N/A	Meta greywacke
L16	NO	30%	40%	Max % market driven – dependant on customer, workability and finishing requirements. In winter, use of a higher proportion of manufactured sand may be possible. Latite
L24	NO	70%	N/A	Washed Latite (probably altered)
N53	NO	20%	50%	Washed?? Granite
S51	NO	20%	50%??	Utilised surplus stocks – not purpose made as manufactured sand Limestone/dolomite
S68	NO	100–200 kg	25%	12.5 to 25% Limestone/dolomite
T68	NO	100–200 kg for kerb mix 400–600 kg for shotcrete 100–150 kg for 'N' Class	25% 75% 18.75%	12.5 to 25% 50 to 75% 12.5 to 18.75% Quartzite
Nepean River sand	NOT USUALLY	80% to 90%	None	Washed river sand; typically includes up to 15% of washed crushed river gravel dust Coarse, graded quartz river sand
Kurnell Dune sand	NOT USUALLY	10% to 20%	40%	Washed dune sand Medium to fine, single size, sub rounded quartz sand

1.5 TEST METHODS AND RELEVANCE TO MANUFACTURED SAND

1.5.1 Micro Deval

The report on the first stage concluded that:

> *At the conclusion of this project it still remains true that no one 'durability' test for fine aggregate will assess all parameters of 'durability' required for aggregate and product performance.*

One of the parameters that needs determination is:

- Resistance of the aggregate to abrasion and breakdown while being handled and placed and resistance to abrasion in place. This is of particular significance for asphalt aggregate and fine filter aggregates but has some significance for concrete aggregate. At the present time the Mini Deval appears to have the greatest promise in evaluating this parameter.

Existing methods for assessing aggregate durability are not capable of determining the resistance of a fine aggregate to abrasion and so the first report recommended that:

> *A separate project is recommended to investigate the application of the Micro Deval test to manufactured sands. Overseas research suggests that the test has a great deal of promise, is reliable and relatively inexpensive. The test is reported widely in asphalt applications and may offer a useful control in solving one of the RTA's concerns, namely the evaluation of abrasion resistance in fine aggregate used in concrete road pavements.*

The Micro Deval test is well described in 'Aggregate tests for Portland Cement Pavements' *National Cooperative Highway Research Program Research Results Digest* No. 281, Sept 2003 Number 281 as follows:

> 'The Micro Deval test appears to be the best indicator for assessing the potential for aggregate breakdown. This method was developed in the 1960s in France, has been used extensively in Canada, and is now included in the Canadian Standards Association (CSA) specifications. It is a wet attrition test that is available in two versions, one for fine aggregates (CSA A23.2-23A – *Resistance of Fine Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus*) and one for coarse aggregates (Ontario MOT Test LS-618, *Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus*). The coarse aggregate version of this test is now available as AASHTO TP58 (*Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus)*. The test subjects an aggregate sample to wet attrition by placing it in a steel jar with steel balls (9.5 mm in diameter) and water, then rotating the jar at 100 rpm for 2 hours for coarse aggregates or 15 minutes for fine aggregates. Aggregate damage is assessed by mass loss at the completion of the test using a 1.25-mm sieve and a 75-μm sieve for coarse and fine aggregates, respectively.

> 'The Micro Deval test for fine aggregates has been found to correlate well with magnesium sulphate soundness testing but has better within and multi-laboratory precision and is less sensitive to aggregate grading (Rogers et al,1991). Specifications stipulate a maximum loss for fine and coarse aggregates.'

1.5.2 LCPC packing density

this test result is a critical design input for a new concrete design procedure developed by the *Laboratoire Central des Ponts et Chaussées* (LCPC). The theory of the design method is best described by Francois de Larrard and Thierry Sedran in 'Mixture-proportioning of high performance concrete' *Cement and Concrete Research* May 2002. In very simple terms, the design method models the plastic concrete mix as a framework of coarse and fine particles through which the binder (which includes the cement, admixtures, SCMs, water and aggregate microfines) penetrates as a rheological fluid. Aggregate microfines are defined as all material in the aggregate grading finer than 75 micron. Modelling of the interaction of the framework and the binder can be used to design for strength, shrinkage, porosity and workability of the mix.

The packing density test for all aggregate sizes provides the design criteria that allows for the calculation of the aggregate framework and determination of the void space in the framework that will be filled with the binder. The design method is available in Australia as 'BetonLab'.

The packing density test, designated LCPC Test No. 61, is applied to both coarse and fine aggregates. A sample of aggregate is compacted into a cylinder using a specified placement and compaction procedure. Following compaction, the height of the compacted mass of aggregate is determined, enabling the compacted volume to be calculated. The mass of aggregate is determined at the same time, enabling the compacted unit mass to be calculated.

By comparing this result with the particle density of the aggregate, a relative density figure is obtained, ie the unit mass as a proportion of the particle density. This ratio is known as the 'Packing Density' and is clearly an inverse of a voids calculation for the material at the specified compaction.

There is no specification for the test because the test is not intended as a means of certifying or selecting aggregate of any particular quality. The test is designed to provide an input to a design and, in theory, any aggregate could be accommodated by the procedure.

1.6 TEST RESULTS

Testing for this stage of the project was carried out at Hanson's laboratory at Wallgrove and at Cemex laboratories at Northmead and Penrith between November 2006 and June 2007. Testing was conducted in accordance with published methods, LCPC Method 61 for the Packing Density test and CSA A23.2-23A for the Micro Deval. The results of the testing are summarised in **Tables 1.3 and 1.4**. Original laboratory reports have been supplied to CCAA.

Data from the LCPC tests for Stages 1 and 2 of this project is given in **Table 1.3** and **Figure 1.1**. The report to Stage 1 had suggested that the LCPC density measured the inverse of voids in the compacted aggregate and the data was compared with the Voids measurement from the NZ Flow Cone. However, as no correlation returned an R^2 coefficient greater than 0.2, the analysis is not reported.

Micro Deval results are reported in **Table 1.4** and are compared with other 'durability' measures reported for the selected samples taken from the report on Stage 1 of this project

TABLE 1.3 LCPC packing density test results

SAMPLE CODE	ROCK TYPE	LCPC PACKING DENSITY: Hanson Stage 1 a	b	Av	Hanson Stage 2 Test 1 A	b	Av	Hanson Stage 2 Repeat test a	b	Av	Cemex Stage 2 a	b	Av
D69	Rhyodacitic tuff	0.651	0.654	0.653	0.652	0.653	0.653	0.637	0.637	0.637	0.638	0.657	0.647
S51	Limestone	0.654	0.653	0.654	0.648	0.65	0.649	0.631	0.633	0.632	0.649	0.645	0.647
L16	Latite	0.644	0.647	0.646	0.65	0.65	0.65	0.636	0.634	0.635	0.653		0.653
N53	Granite	0.644	0.666	0.655	0.668	0.669	0.669	0.653	0.651	0.652	0.667	0.671	0.668
G80	Meta greywacke	0.642	0.639	0.641	0.65	0.65	0.65	0.632	0.635	0.634	0.649	0.636	0.642
L24	Latite	0.65	0.644	0.647	0.66	0.661	0.661	0.635	0.638	0.637	0.644	0.644	0.644
S68	Limestone	0.626	0.626	0.626	0.625	0.625	0.625	0.604	0.608	0.606	0.606	0.611	0.609
T68	Quartzite	0.655	0.654	0.655	0.672	0.673	0.673	0.659	0.661	0.657	0.661	0.661	0.661
Control	Quartz sands				0.692	0.691	0.692	0.676	0.677	0.677	0.685	0.682	0.684

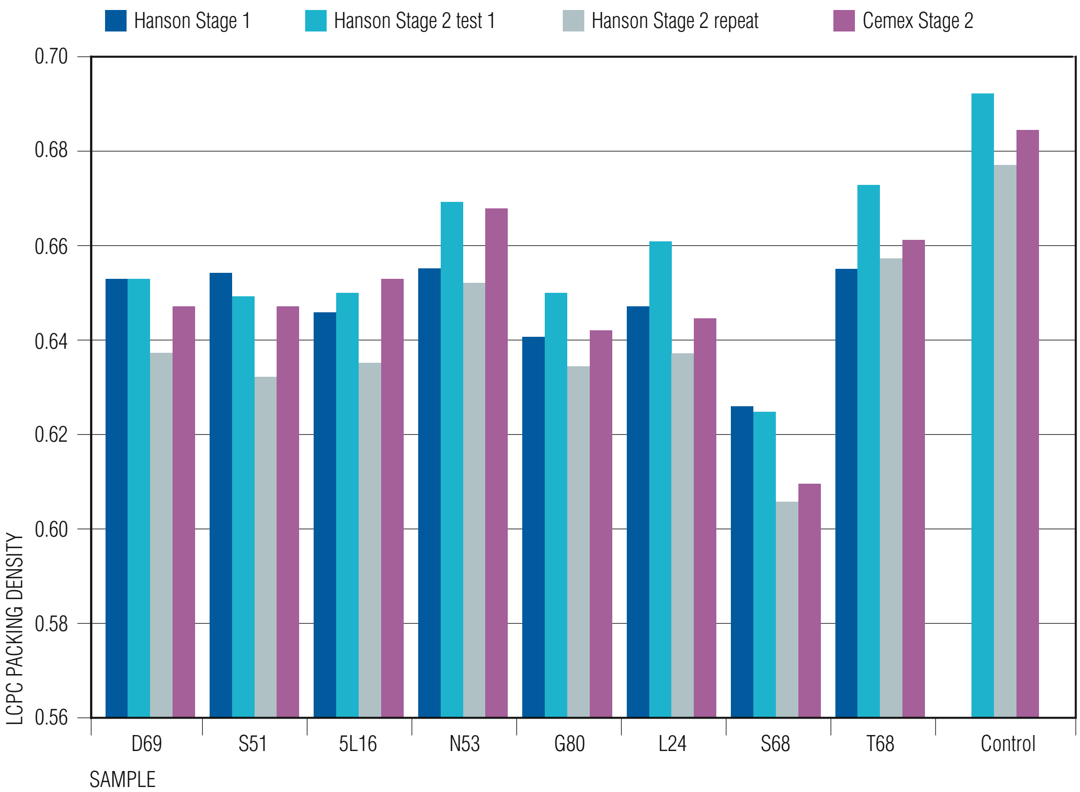


FIGURE 1.1 LCPC packing density test results

TABLE 1.4 Micro Deval and durability properties of selected manufactured sand samples

Sample	Rock type	Mass % passing 75 micron	MBV	MBV x % passing 75 µm	Sodium sulphate loss (%)	Degradation factor (fines)	Sand equivalent	Micro Deval loss (%)
D69	Rhyodacitic tuff	9.0	3.4	30.0	0.4	85.0	74.0	8.4
S51	Limestone/dolomite	8.0	1.2	8.0	0.2	89.0	81.0	23.2
L16	Latite	10.0	10.8	108.0	1.4	88.0	88.0	14
N53	Granite	11.0	12.0	121.0	0.7	90.0	90.0	8.9
G80	Meta greywacke	12.0	11.8	141.6	0.7	86.0	66.0	9.7
L24	Latite (probably altered)	17.0	11.4	193.8	1.1	84.0	60.0	20.4
S68	Limestone/dolomite	23.0	14.3	322.0	1.3	74.0	40.0	26.1
T68	Quartzite	19.0	24.2	456.0	6.0	53.0	25.0	17.2
Control	Quartz rich sands							10.0

1.7 DISCUSSION OF RESULTS AND SPECIFICATION CONFORMANCE

1.7.1 Micro Deval testing

General The data presented in **Table 1.4** shows that for this set of nine samples, there is no correlation between the Micro Deval results and the remainder of the durability measures. This conclusion is not supported by overseas research where reasonable correlation of Micro Deval with magnesium sulphate loss and sodium sulphate loss is regularly reported. As might be expected, Micro Deval results correlate well with Los Angeles abrasion results.

The lack of correlation in the case of this set of samples is simply due to the very small sample set and to the selection process that did not consider the rock type of the samples.

The results are quite significant. For this set of data, they demonstrate that the Micro Deval is not as influenced by adverse mineralogy as are other durability measures. Instead, it appears to be controlled by the 'softness' of the rock. Even though the S51 limestone sample is a durable aggregate by all other measures, the soft rock fabric means that the material can be abraded and the Micro Deval loss is high. Where alteration or weathering has weakened rock fabric in rock types that might be strong in an unaltered material, the Micro Deval records higher values (samples L24 and T68).

The influence of rock type on the Micro Deval loss has been identified in overseas research, particularly in the work of Senior and Rogers in Ontario. Following the testing of 106 samples they attributed some differences in results to rock type. A specification developed for the Ontario DoT is structured to provide differences in limits for different rock types.

With only eight samples tested in the CCAA research, and with the selection of rock types being very atypical of the most commonly used rocks in Australian civil works, there is insufficient data to make anything other than the most general comments on the influence of rock type, or on the usefulness of the Micro Deval test method.

Other documents were examined in relation to Micro Deval specifications.

Specifications A search of overseas papers has provided only limited specification examples for Micro Deval limits for fine aggregates (but a more extensive set of limits for coarse aggregate). From the papers examined, the current state of specifications is best summarised as:

- Only one specification was found, that of Ontario, which had different specification limits for different rock types. At this very early stage of investigating the test in Australia, there is neither sufficient data to support this distinction, nor any evidence that the distinctions identified in Ontario would apply to Australian rock types.
- For use as bedding sand under interlocking blocks in heavy load environments, the Interlocking Concrete Pavement Institute (ICPI) specifies a maximum Micro Deval loss of 8%. These limits have been applied in Australia for work at international airports at Cairns and Sydney, but using a different (although very similar) test procedure to the Micro Deval
- AASHTO and some US states are specifying a maximum Micro-Deval loss of 10% for high volume traffic (eg motorways and major highways) using PCC or asphaltic concrete road surfacing.
- Most specifications limit Micro Deval to a maximum loss of 17%.

There does not appear to be any distinction made in any of the specifications sighted between a loss applying to the fine aggregate as a whole or to any component of a fine aggregate blend.

1.7.2 LCPC packing density tests

General There is no specification for this test procedure, either in Australia or in France, because the test is not used as a means of selection of suitable material or for rejection of deleterious material. The test provides design data necessary for the use of the BetonLab design method and the test was included in this programme in anticipation of subsequent trialling of mix designs by BetonLab in a later part of the CCAA research into manufactured sand. Although the first stage of the project had concluded that the LCPC packing density test could not be used for manufactured sand specifications, the subcommittee decided to use this second stage to collect additional data on this test procedure. The design of the second part of Stage 2 that would evaluate these samples in mortars, had intended to use one mortar design based on the BetonLab programme. At the time of designing this project, the subcommittee understood that the LCPC packing density was the only additional data item required for the BetonLab programme. However, in addition to the packing density of the plus 75 micron sized material, it is also necessary to determine the particle size of the sub 75 micron fraction using laser sizing techniques and to determine the packing density of the sub 75 micron fines. Even with the testing conducted in the first stage of the project, it was not possible to use the BetonLab programme in the later project without conducting more-sophisticated testing and the subcommittee chose not to undertake with this additional work. Thus, as all of the data required for a BetonLab design was not collected, this use of the data never eventuated.

The results cover a limited range; this is not unexpected as the manufactured sands are of similar top size and are produced from comparable processes.

Any dry aggregate compacted into a cylinder will form a skeleton of solid particles and the remainder of the space will be voids. Measurement of the unit mass of the aggregate and knowing the particle density of the aggregate allows for calculation of the voids. The scope of AS 1141.16 *Angularity Number* states:

> '...after compaction in the prescribed manner. The least angular (most rounded) aggregates have about 33% voids'. In terms of the LCPC results, 33% voids would be equal to a packing density of 0.6, while higher voids caused by more-angular material or significant changes in grading would result in lower density ratios. The LCPC numbers appear a little high in comparison to the information from Method 16 (the expectation would have been for numbers perhaps as low as 0.57). However, it is probable that this difference is the result of different compaction techniques.'

Francois De Larrard, who was responsible for the development of the BetonLab models and design method, reports packing densities ranging from 0.543 for a 4/10-mm aggregate and 0.57 for a 10/20-mm aggregate through to 0.778 for a very well graded mix of rounded sand and 5-mm aggregate. Based on this information, the results reported for the graded but angular manufactured sands tested in this project appear to be of the right magnitude.

The report on Stage 1 of this project had stated that the LCPC packing density was effectively the inverse of a voids ratio calculation. The results reported in this stage of testing were compared with the voids data generated by Hanson's laboratory in the first stage when all samples were tested by the NZ Flow Cone procedure. As has been noted in Section 1.6, the correlation coefficient for this comparison was less than 0.2 when all data was considered. However, when the data for sample L24 was excluded, the plot of some of this data in **Figure 1.2** illustrates the expected correlation between the voids measure and the LCPC packing density. For the sake of clarity, only two data sets are shown, but the remaining data has similar correlation coefficients. The compaction process in the LCPC procedure reduces the voids content by approximately 20% compared to the loose packing of the Flow Cone procedure.

Repeatability and Reproducibility One of the aims of this stage of the project was to collect data relating to the repeatability and reproducibility of the test procedure. Repeatability is defined as the difference that might be expected in reported results between two tests conducted on split samples using the same equipment within the same laboratory. Reproducibility is the difference in two reported results conducted on split samples at different laboratories. Within the limits of the project budget and the number of laboratories participating, it was not possible to satisfy the conditions of ASTM C802–96 *'Conducting an Interlaboratory test Program to Determine the Precision of Test Methods for Construction Materials'*. However, sufficient data was collected to provide an indication of the variation in test data.

The committee accepted an experimental design for this stage that required the testing laboratory to retain the manufactured sand samples after conducting the LCPC packing density test and to retest the samples after about one month using the same equipment but a different technician. Hanson's laboratory has reported these results and has included for comparison the results of the packing density tests from the Stage 1 tests. Cemex completed only the first test for this stage and had not tested any samples in Stage 1 of the project (see **Table 1.3** and **Figure 1.1**).

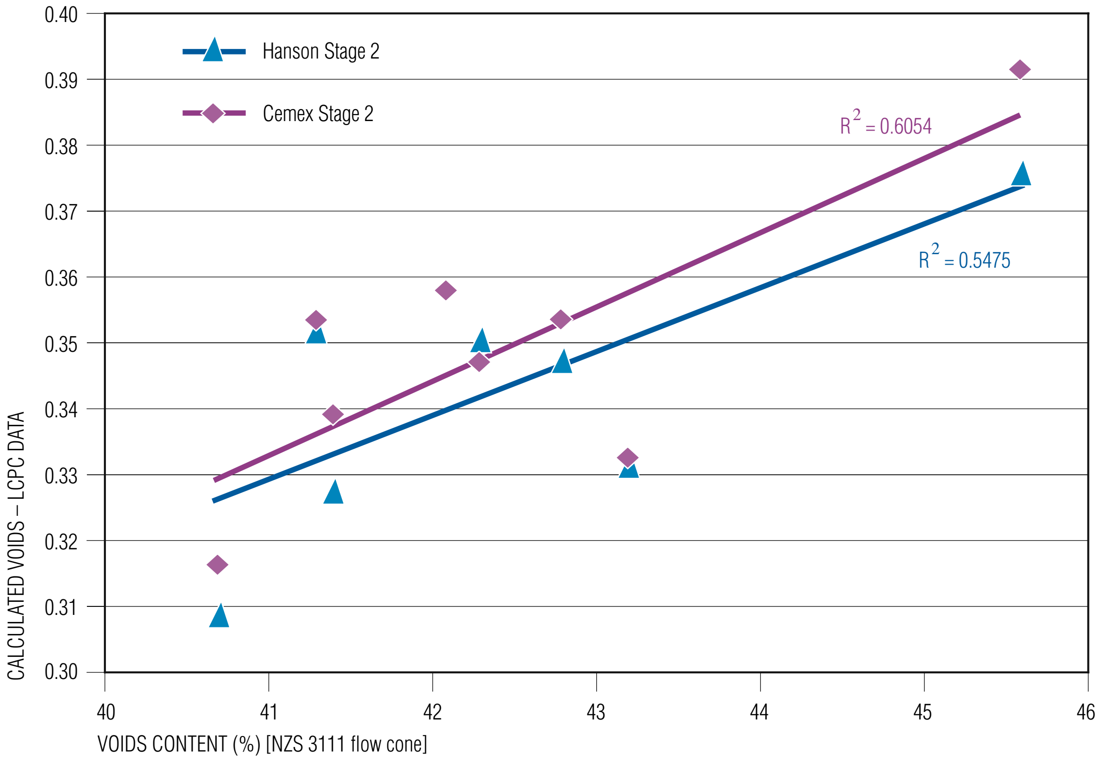


FIGURE 1.2 Correlation between measured voids and LCPC packing density

Examination of the Hanson data for this stage indicates a regular difference between *Test 1* and the *Repeat* with all *Repeat* results lower on average by 2.6%. The fact that all results are lower tends to indicate a systematic error and it may have been assumed that the error was the result of the change of technician. However, Hanson notes that the difference may be the result of breakdown of particles in the sample caused by the first compaction. The breakdown of particles could result in a systematic error. This possibility had not been anticipated in the experiment design, the cause of the difference in these two sets of results is therefore uncertain.

To gain some appreciation of the difference that might be expected between the results of two tests conducted on split samples in the same laboratory, all the duplicate determinations were treated as a single data set. In each LCPC determination, each sample is split and the test is conducted on each split. The average of the two determinations is reported as the Packing Density. Calculating the range of the pair of determinations and dividing by the average of the pair (ie the variation of the result), and then averaging this over the full data set in **Table 1.3**, gives a measure of an expected variation in the method.

For this data set, the average variation was 0.51%, with a minimum variation of zero and a maximum variation between a pair of determinations of 3.4%.

However, the repeatability is defined as the variation in the reported result, which for the LCPC test is the average of the pair of determinations. The data presented in **Table 1.3**, includes two sets of LCPC results, conducted at the same (Hanson's) laboratory, that can be compared. The first set of eight pairs compares the data determined in Stage 1 of the project with the data generated in Stage 2. Although these test samples were drawn from the same bulk sample and Hanson had made some effort to homogenise the bulk sample, it could be argued that the test samples are not strictly split samples

For these eight samples, the average variation is 1.2% with a minimum variation of 0 and a maximum 2.7%

The second set of nine data pairs is that where the test was performed and then repeated on the same sample at the same laboratory by a second technician. As already discussed, this data set may be affected by breakdown of particles. For this data set, the repeat sample is lower in all cases.

For these nine data pairs, the average variation is 2.6% with a minimum variation of 2.2% and a maximum variation of 3.7%.

The only set of data that approaches that required to determine reproducibility is that between the first test at Hanson on the Stage 2 test sample and the testing performed by Cemex. These pairs of samples were prepared as splits, but for an ASTM determination of reproducibility, tests are usually conducted at no less than six laboratories.

For the nine data pairs, the average variation was 1.2%, the minimum variation was 0.15% and the maximum variation was 2.6%.

Although the data does not allow for an assessment of test precision, it would appear that the test variation is unlikely to exceed 5%. By comparison with a number of engineering tests, this result is quite favourable. However, as the research programme has not used the BetonLab analysis for any of these materials, no information on whether a 5% uncertainty in the packing density would cause any significant difference in a BetonLab mix design was available.

1.8 CONCLUSIONS

1.8.1 Micro-Deval test

- The very limited set of Micro Deval data generated in this project has indicated that the test is influenced by factors other than those measured by other available durability tests for fine aggregate.
- Specification limits for the test are noted in overseas papers and specification documents but the data generated in this project is inadequate to provide any basis for determining if the limits could be applied in Australia.
- This project has used only a single laboratory. Although overseas research notes high precision for the test, there is no verification of precision data for Australia.
- The Micro Deval test has the potential to be used as an Australian standard method; however, further work will be required before this can be recommended.

1.8.2 LCPC packing density test

- The LCPC packing density test appears to be highly repeatable and is probably quite reproducible although the data generated in this project was not sufficient to allow for an assessment of these parameters in strict accordance with ASTM.

- None the less, the addition of the relatively simple LCPC packing density test is not of itself sufficient, along with other commonly used Australian test methods, to allow a concrete specifier, designer or producer to make use of the BetonLab design procedures.
- There is no French or Australian specification limit for the packing density test; nor does the test appear to provide a measure of any parameter that should lead to rejection of an aggregate for use in a concrete mix.
- As it is unlikely that the CCAA research would extend to investigating the BetonLab design procedure, there is no obvious benefit in CCAA continuing any further research into the Packing Density test.
- Unless the BetonLab design is being used, the Packing Density test has little application in Australia.

1.9 RECOMMENDATIONS

It is recommended:

1 That no further research into the LCPC packing density test be undertaken.

2 Using Micro Deval, test as many sources of fine aggregates as possible. Eventually the test may be used for coarse asphalt and sealing aggregates.

3 Before recommending Micro Deval for inclusion in Australian Standards, an investigation of the precision of the test be undertaken.

4 The correlation between Micro Deval results and the abrasion resistance of both concrete and asphalt pavements be established.

2 Concrete mortar investigation

2.1 INTRODUCTION

The design of the first stage of the research project allowed for the retention of sufficient material from each source sample to allow for additional research. Eight samples were selected from the original twenty one, with the recommendation that further research be conducted on these samples. This further research investigated the effects of the physical and mineralogical properties of the samples on the performance of cement mortars. The first stage of the project defined some acceptance limits for manufactured sand. This part of the second stage investigated the maximum quantity of manufactured sand of known physical properties that could be used in a blend with a clean, fine, natural sand.

The Sydney market is considered the next region likely to experience a significant growth in the use of manufactured sand. For this reason the trial natural sand will be Kurnell dune sand which is readily available in the Sydney market.

2.2 OBJECTIVES

This part of the research project had the following objectives:

1. To determine the effects of measured properties of manufactured sand on the plastic and hardened properties of cement mortars in absolute terms and in comparison with the properties of a control mortar using a sand blend in common use in the Sydney market.
2. To estimate the limit blends of the sample manufactured sands by comparison with current concrete supply using a structured trial programme.

2.3 METHODOLOGY

This stage of the project tested eight sources of manufactured sand selected on the basis of measured physical properties from the samples supplied to the first stage of the project. The samples and their measured properties are detailed in **Table 1.1**. The samples selected represented the full range of physical and mineralogical properties (see **Table 2.1**) measured in the first stage of the project. From the information supplied on the use of manufactured sand (see **Table 1.2**), typical proportions range from 15% to 100% of the fine aggregate (See **Table 2.3**).

The manufactured sand samples were tested as the fine aggregate components of cement mortars. Each sample was tested as 100%, 50% and 20% of the sand in the mortar. Where the manufactured sand was less than 100% of the sand component, the remainder of the fine aggregate blend was Kurnell dune sand.

The bulk of the mortar testing was conducted at the Readymix (now Cemex) concrete laboratory at Northmead, NSW with some further tests conducted at Boral's laboratory at Baulkham Hills, NSW. Both laboratories established the water demand for the mortars tested using the flow table defined in AS 2701.7. The flow specified for this research was 110±3%.

However, from this point the procedures used by the two laboratories diverged, following the practice used by the two companies. Cemex laboratory prepared mortar using the procedures described in Appendix 1. Boral's laboratory followed the procedures given in Boral Standard Method 1 *Determination of water requirement, relative strength, and relative drying shrinkage.* This method is included in **Appendix 1**.

TABLE 2.1 XRD results for samples for mortar trials

	SAMPLE NUMBER															
	D69		S51		L16		N53		G80		L24		S68		T88	
MINERAL	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis	Head sample analysis	<75 µm sample analysis
Quartz	CD	CD	Tr		Tr		D	D	SD	SD	Tr		CD	SD	D	D
Plagioclase	CD	CD			D	D	SD	SD	D	D	D	CD	A	A	Tr-A	SD
K-feldspar	A	A			SD	SD	A	A	A	A	A	CD	A	Tr-A		
Clinopyroxene					A	SD						CD				
Olivine																
Amphibole							Tr	Tr								
Analcime																
Laumontite																
Stilpnomelane																Tr
Muscovite	A	A							A	Tr				Tr	Tr	Tr
Biotite							A	A								
Chlorite	Tr-A	A					Tr		A	A			A	A		
Kaolinite															Tr	Tr
Smectite					A	A		Tr-A			A	A				
Calcite		Tr-A	D	D					Tr	Tr-A			CD	D		
Clay Minerals in the clay fraction (<2 µm)																
Mica (illite)	D	D		CD			D	D	CD	SD			D	D	D	D
Chlorite	A	A					A	Tr-A	D	D			SD	SD	A-SD	A
Kaolinite			D	CD	SD	SD					A-SD	SD				
Smectite					D	D	SD	A	SD	A	D	D	A-SD	A		Tr
Clay Minerals in the clay fraction (<2 µm) – Percentages																
Mica (illite)	90	80		50			50	80	40	30			50	50	80	75
Chlorite	10	20					10	5	40	60			30	30	20	20
Kaolinite			100	50	30	40					20	30				
Smectite					70	60	40	15	20	10	80	70	20	20		5

Semiquantitative abbreviations:

D = Dominant. Used for the component apparently most abundant, regardless of its probable percentage level.

CD = Co-dominant. Used for two (or more) predominating components, both or all of which are judged to be present, in roughly equal amounts.

SD = Sub-dominant. The next most abundant component(s) providing its percentage level is judged above 20%.

A = Accessory. Components judged to be present between the levels of roughly 5 and 20%.

Tr = Trace. Components judged to be below about 5%.

The Boral Standard method uses a 'Control Mortar' as part of the procedure to enable the calculation of 'relative water demand', 'relative strength' and 'relative shrinkage'. For the purposes of this research the 'Control Mortar' was prepared with a blended fine aggregate composed of 80% by mass of Nepean River Sand and 20% by mass of Kurnell fine sand. This blend is similar to a blend that has been used extensively in the Sydney market. All mortars in the research were prepared without the use of SCMs and admixtures. Cemex laboratory used the same control mortar but prepared according to the procedures described in Appendix 1 and tested by the procedures described below.

Both laboratories prepared specimens of all mortar blends for strength testing at 28 days except that there was insufficient L16 material for Boral to prepare mortar mixes for the 50% and 20% blends. Cemex's test specimens were prepared as 50-mm cubes while Boral's specimens were cast as 40- x 40- x 160-mm prisms in accordance with AS 2350.12.

Cemex laboratory conducted shrinkage testing on all mortar blends to 56 days. Shrinkage specimens were cast in moulds conforming to those specified in AS 1012.13 for drying shrinkage of concrete and testing was conducted to this method. Specimens measure 75 x 75 x 280 mm. Boral conducted shrinkage tests on the mortar mixes only where the manufactured sand represented 100% of the fine aggregate. Specimens were cast and tested in accordance with AS 2350.13 and the specimens measure 40 x 40 x 125 mm.

In addition to relative water demand, relative strength and relative shrinkage, each mortar mix was tested for bleeding and for setting time. Calculations were determined for the water-cement ratio of the mix and measurements were made of the hardened density of the strength specimens.

During the process of casting specimens of the mortars, the workability of the mixes in relation to the control mortar was evaluated. This subjective measure compared the difficulty of working and finishing the mortar and the 'off-trowel finish' achieved on the specimens.

Although the physical properties of the manufactured sands were measured in the first stage of this project, the physical properties of blends of manufactured sand and natural sand used in this stage have not been evaluated. For most properties it is expected that simple proportioning will be sufficiently accurate for the purposes of this research. However, the results of the Flow Cone test could not be determined by proportioning. It was therefore necessary to produce samples of each proposed blend and physically test the material to determine Flow Cone results.

2.4 PROJECT SAMPLES

The samples used in this project were a subset of the samples used in the first stage of the CCAA research project on manufactured sand. The data given in **Table 1.2** is reproduced from Table 3 of the report on the first stage. Sample identification is unchanged from the first stage. In order to explain the results of the Micro-Deval test, the rock type for each source had to be identified even though this information was not available at the time the samples were selected. This information has been included in **Table 1.2** along with comparable data on the sands blended to produce the control sample.

2.5 TEST METHODS AND RELEVANCE TO MANUFACTURED SAND

The report on the first stage of the CCAA manufactured sand research project discusses the test methods used to assess manufactured sands as raw materials. The methods are described in that report along with a discussion of the usefulness of the test in specifying the sand.

The properties of the cement mortars evaluated in this research were measured using Australian standard methods. All mortar mixes were controlled by the flow of the mortar measured on a mortar flow table described in AS 2701.7 *Methods of sampling and testing mortar for masonry constructions – Method 7: Method for determination of water retention.* All mortars were prepared to have a flow of 110±3%. Following preparation of the mortars, Cemex conducted measurements of bleed using the procedure of AS 1012.6 – 1999 *Determination of bleeding of concrete* and determined the setting time of the mortar using AS 1012.18–1996 *Setting time of fresh concrete, mortar and grout by penetration resistance.*

As part of the research brief, the contracted laboratory was asked to provide a measure of the 'workability' of the mortar. The ability of the contractor to easily finish the placed concrete has been identified as a significant issue, particularly for concretes used in domestic construction (typically low strength mixes, placed directly from agitator trucks or from low-volume, small-diameter pump lines and placed by contractors on job sites without project management controls) or for off-form finishes. Mortars containing manufactured sand might be expected to be more difficult to finish because of the presence of irregularly shaped particles in the coarse end of the sand grading, compared with the sub rounded to rounded grains of most natural sands. This shape difference is expected to increase the water demand of any mix containing a significant proportion of manufactured sand and to increase the difficulty of finishing the concrete to any desired surface texture.

Cemex Laboratory addressed this requirement by comparing the difficulty of finishing test specimens across the range of mixes tested. Experienced technical staff were asked to record their impressions of the difficulty of completing the surface finish of cast prisms. An arbitrary scale of 1 to 10 was established for ranking the difficulty of finishing the specimens with 5 being neutral, 1 being most difficult, and 10 being 'self levelling'. Photographs were taken of all specimens but the detail and contrast of the photos is not sufficient to distinguish between rated specimens.

As discussed later, the rating of the mixes and the comments made can be related to the more traditional empirical mix tests and to some extent to the physical tests conducted on the manufactured sands as raw materials. There is a need for an objective, reproducible procedure for assessing the workability of mortars and concrete, but until such a procedure is developed, the observations of finishing are of significant relevance to the development and use of manufactured sands.

The Boral Standard Method 1 was used by Boral Laboratory in this research. The procedure combines aspects of a number of Australian Standard mortar methods in order to relate the hardened properties of the mortar to a control mortar. It is assumed that the control mortar has properties that are acceptable in the market.

The mortars are prepared as a standard mix by mass of the sand under test and portland cement with sufficient water to achieve a flow of 110±3%. The mortars are prepared following AS 2350.12 *Methods of testing Portland and blended cements – Method 12: Preparation of a standard mortar and moulding of specimens.* The mortar flow is determined following AS 2701.7 *Methods of sampling and testing mortar for masonry construction – Method 7: Method for determination of water retention.* Specimens are cast and tested for compressive strength following AS 2350.11 *Methods of testing Portland and blended cements – Method 11: compressive strength.* Further specimens are cast and tested to measure the drying shrinkage of the mortar following AS 2350.13 *Methods of testing Portland and blended cements Method 13: Determination of drying shrinkage of Portland and blended cement mortars.*

The test procedure compares each mix with a control mortar and calculates the strength and shrinkage of each mix as a percentage, relative to the results for the control. For the purposes of this research the control sand was a blend of 80% Nepean River sand and 20% Kurnell sand. Current production of Nepean River sand contains approximately 15% of washed crusher dust resulting from the crushing of the Nepean River gravels. This blend of control sand approximates a sand blend that would be realistic for the Sydney market, with the percentage of Kurnell sand varying in many mixes between 10% and 20% of the total fine aggregate. Kurnell sand was chosen as the blending sand for this research because it is a known, readily available fine dune sand representative of much of the coastal dune sand that is currently available or may become available to the industry in the Sydney market.

Cemex laboratory used a mortar preparation procedure that varied slightly from the procedure used by Boral but it is not expected that these differences are wholly responsible for the differences in water demand noted between the two laboratories.

Similarly, the difference in mould size for strength tests has caused differences in strength results that cannot be separated from the differences that may be expected from the variation in water-cement ratio between the two laboratories for comparable mixes. Both sets of strength specimens are recognised in a variety of methods; this report does not add to the debate on the relative benefits of different specimen aspect ratios. It is clear from the discussion following that either method has demonstrated the relationship between the properties of the manufactured sands, the water demand of the mortar mixes and the strength of the mortar specimens and that is sufficient for this research.

Differences in the mould sizes for shrinkage tests resulted in significant differences in reported shrinkage at the same age. However, a model of concrete shrinkage reported by Gilbert ('Creep and shrinkage models for high strength concrete – proposals for inclusion in AS 3600'; *Australian Journal of Structural Engineering* Vol. 4, No. 2) allowed for a correction of reported values to account for the differences in mould size. The resulting analysis discussed in Section 2.6 demonstrated a clear relationship of shrinkage to water demand, and the relationship of water demand to some measured physical properties of the manufactured sand.

The CCAA research has as a basic objective, to define the effects of using manufactured sands on the properties of concrete. In order that a wide range of manufactured sand properties was considered and to provide relevance nationally, manufactured sands from a wide range of source rocks and from geographical locations that spanned the continent, were tested and evaluated in the first stage of the research project. The samples selected for this stage of the research were chosen on the basis of these measured physical properties. The intention was to choose material for the mortar trials that spanned the range of physical properties measured from the national sampling of manufactured sands already being used in the market. No reference was made in the selection to either the geographic location of the source or to the rock type. For this reason, the data does not specifically address the Sydney market even though a Sydney sand was used for blending and a Sydney sand blend was used as the control.

Mortar tests were used so as to indicate the probable impact of the manufactured sand on concrete. Testing mortars composed of only the manufactured sand, the cement and water reduces the number of variables involved in the test data. Although it is certain that the effect of the manufactured sands will be altered in concrete by the effects of the coarse aggregate, by different blending sands, by SCMs and by admixtures, these mortar results define the direct impact of the sand on the plastic and hardened properties of the mix. The mortar results are unlikely to correlate with the properties of any specific concrete because of the introduction of all the other mix variables, but they will indicate in general the trend of influences resulting from the use of a manufactured sands of given properties.

The mortar tests conducted in this research address only what might be loosely described as the design properties of the mix, namely strength, shrinkage and workability as measured by flow and the subjective rating mentioned above. No tests were conducted which might have evaluated properties related to long-term durability or to special properties of the mortar or, by implication, a concrete. Such properties might include permeability, sorptivity, and resistance to adverse chemical or environmental conditions, or resistance to wear.

2.6 DISCUSSION OF TEST RESULTS

A summary of all test results is provided in **Appendix 2**.

2.6.1 Water demand

The water demand of the mortars prepared for this research is defined as the calculated free water above the saturated surface-dry condition of the fine aggregate, required to hydrate the cement and to provide a mortar flow of 110±3% measured on a flow table described in AS 2701.7. The water demand of the mortar cannot be correlated to concrete, but it will define the properties of the manufactured sand that will contribute to the water demand of concrete using manufactured sand of the same or comparable physical properties.

Mortar tests were conducted at both Cemex's laboratory and at Boral's laboratory and both laboratories completed calculations of water demand as defined. Comparison of these results for the same mortar mixes is illustrated in **Figure 2.1**. As a general statement, for the same mix, Cemex's results were 7% higher than Boral's.

No attempt was made to isolate the causes of any difference in the water demand determined by the two laboratories. It is probable that the differences are the result of subtle variations in the setup of the flow table. This device is notorious in its inability to provide reproducible results but it remains one of the few devices capable of establishing a consistancy control on mortars. Differences in the method of mortar preparation may have contributed to the measured water demand but again this report has not attempted to isolate these differences.

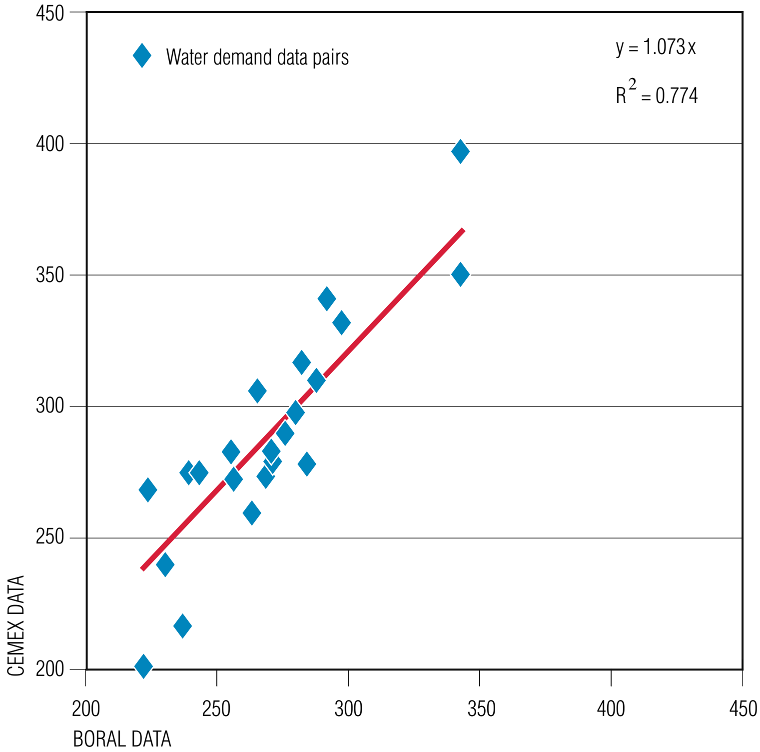


FIGURE 2.1 Water demand data

TABLE 2.2

SAMPLE (mix % of manufactured sand)	**Voids** (%) **NZS 3111**	**WATER DEMAND** (L/m³) **Boral**	**Cemex**	**SAMPLE** (mix % of manufactured sand)	**MBV x 75 µm Multiple**	**WATER DEMAND** (L/m³) **Boral**	**Cemex**
S51 (20)	44.4	263	259	S51 (20)	0.3	263	259
L24 (20)	44.6	255	283	D69 (20)	1.2	265	307
G80 (20)	44.9	282	318	N53 (20)	5.3	287	311
D69 (20)	45.7	265	307	G80 (20)	5.7	282	318
N53 (20)	45.8	287	311	L24 (20)	7.8	255	283
T68 (20)	46.3	279.8	298	S68 (20)	13.2	291	341
S68 (20)	46.5	291	341	T68 (20)	18.5	279.8	298
L24 (50)	39.5	255.8	272	S51 (50)	2.4	236.4	215
S51 (50)	40.1	236.4	215	NRS (80)	2.9	223.2	269
NRS (80)	40.7	223.2	269	D69 (50)	7.7	243.4	275
G80 (50)	40.7	269.3	274	N53 (50)	33	270.8	278
D69 (50)	42.8	243.4	275	G80 (50)	35.4	269.3	274
N53 (50)	42.9	270.8	278	L24 (50)	48.5	255.8	272
T68 (50)	43.6	342.1	351	S68 (50)	82.2	296.2	332
S68 (50)	44.4	296.2	332	T68 (50)	115.9	342.1	351
L24 (100)	37.1	270.1	283	S51 (100)	9.6	221.6	201
S51 (100)	41.3	221.6	201	D69 (100)	30.6	229.7	240
T68 (100)	41.3	699	397	L16 (100)	108	239.4	276
G80 (100)	42.1	284.2	279	N53 (100)	132	276.2	290
L16 (100)	42.3	239.4	276	G80 (100)	141.6	284.2	279
D69 (100)	42.8	229.7	240	L24 (100)	193.8	270.1	283
N53 (100)	43.2	276.2	290	S68 (100)	328.9	343	397
S68 (100)	45.6	343	397	T68 (100)	463.6	699	397

The variation in water demand for the different mixes has implications in the reporting of strength and shrinkage data from the two laboratories; these data are therefore reported separately. However, the general trend in the data remain constant for both laboratories. The subjective measures of workability were conducted only at Cemex's laboratory. It is reasonable to assume that had the workability observations been conducted at Boral, the results would have indicated slightly less workable mortars.

Variation in voids content in the fine aggregate and the reactivity of microfines (defined as the material passing 75 µm) in the fine aggregate were examined as probable causes for the variation in water demand in the mortars. The data for this comparison is reproduced in **Table 2.2**.

Data has been sorted in ascending order of either the Voids content or the multiple of the Methylene Blue Value and the passing 75 µm. The Voids measurement is taken from the New Zealand Flow cone test (NZS 3111) that measure a loose voids content of the manufactured sand as one of the parameters used to establish a classification of sands. The multiple of the MBV and 75 micron was shown in the first CCAA project to be a good measure of the activity of the microfines.

The data given in **Table 2.2** was plotted and the correlation coefficients for a linear fit were calculated. In total six plots were completed for each of the three sets of mix blends (ie 20%, 50% and 100% manufactured sand) against voids content or the multiple. Two example plots are shown in **Figure 2.2** while the correlation data follows as **Table 2.3**.

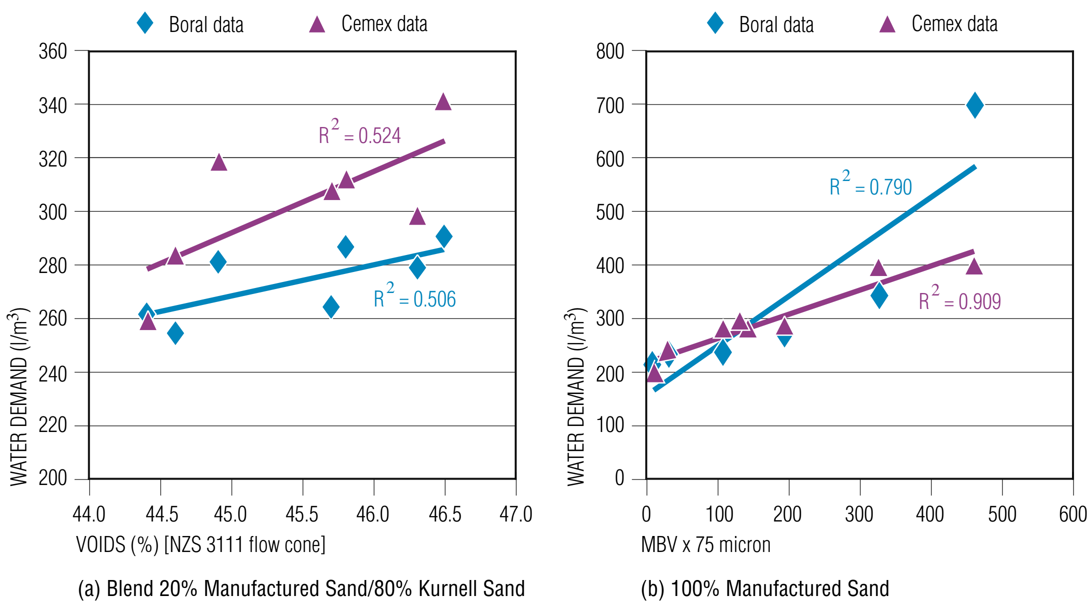


FIGURE 2.2 Example plots of water demand data

TABLE 2.3 Correlation…

MANUFACTURED SAND IN MORTAR (%)	CORRELATION COEFFICIENT (R^2)			
	Water demand vs void content NZS 3111		Water demand vs MBV x 75 micron	
	Boral	Cemex	Boral	Cemex
20	0.506	0.524	0.218	0.155
50	0.433	0.585	0.923	0.796
100	7 x E-05	0.098	0.79	0.909

Table 2.3 indicates that the voids content of the fine aggregate has some influence over the water demand when the percentage of the Kurnell sand is high but has no correlation with water demand for the 100% mixes. By contrast, the microfines activity has little correlation with water demand when Kurnell sand forms 80% of the mix, simply because the Kurnell sand has little to no activity. However, once the manufactured sand becomes significant in the blend, then the microfines activity correlates very well with the water demand.

2.6.2 Mortar strength

At Boral laboratory, strength tests were conducted on mortar prisms; at Cemex they were conducted on 50-mm mortar cubes. Due to the differences in specimen size and because of the higher water content of the mortars produced at Cemex, the 28-day strengths reported by Cemex are, in all cases, lower than those reported by Boral. The relationship between the two sets of results is given in **Figure 2.3**.

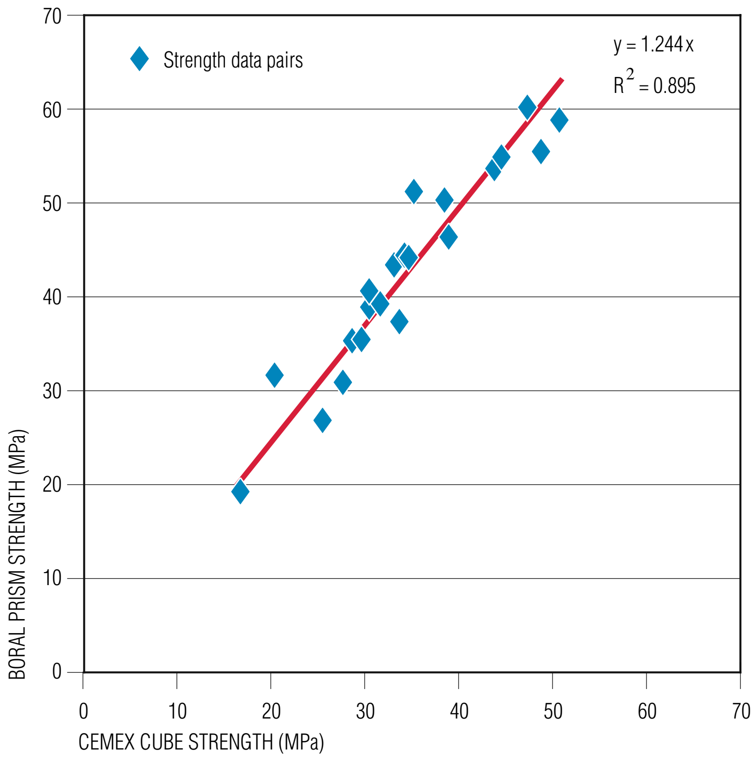


FIGURE 2.3 Correlation of mortar strength data

Typically, strengths from the two laboratories followed the classic relationship between strength and water-cement ratio. Since, in this research, the cement content has been held constant, the water-cement ratio is mirrored by the mix water demand; this relationship for both laboratories is represented in **Figure 2.4**.

A closer examination of the data (see **Appendix 2**) showed that the Boral data for the 50% and 100% mixes all follows the expected trend of increasing strength with lower water-cement ratios. (Except that in the 100% mixes the strength of the T68 sample reported a higher strength than would have been expected from the reported water demand; there was no obvious explanation for this result.

The Boral results for the mixes with 20% manufactured sand (80% Kurnell sand) tended to show a lower strength than may have been anticipated from the similar water-cement ratios in the mixes with 50% and 100% manufactured sand. The probable explanation for the slightly lower strength is in the particle shape of the Kurnell sand. Kurnell is a well rounded, single sized material that would have lower inter-particle friction than the angular manufactured sand. In common with the relationship for rounded coarse aggregate, the Kurnell sand is not as likely to provide good interlock between particles, thus reducing some of the strength of the aggregate skeleton. It is also less likely to provide good bond with the cement paste. For a similar water-cement ratio, the mortar therefore produces less strength.

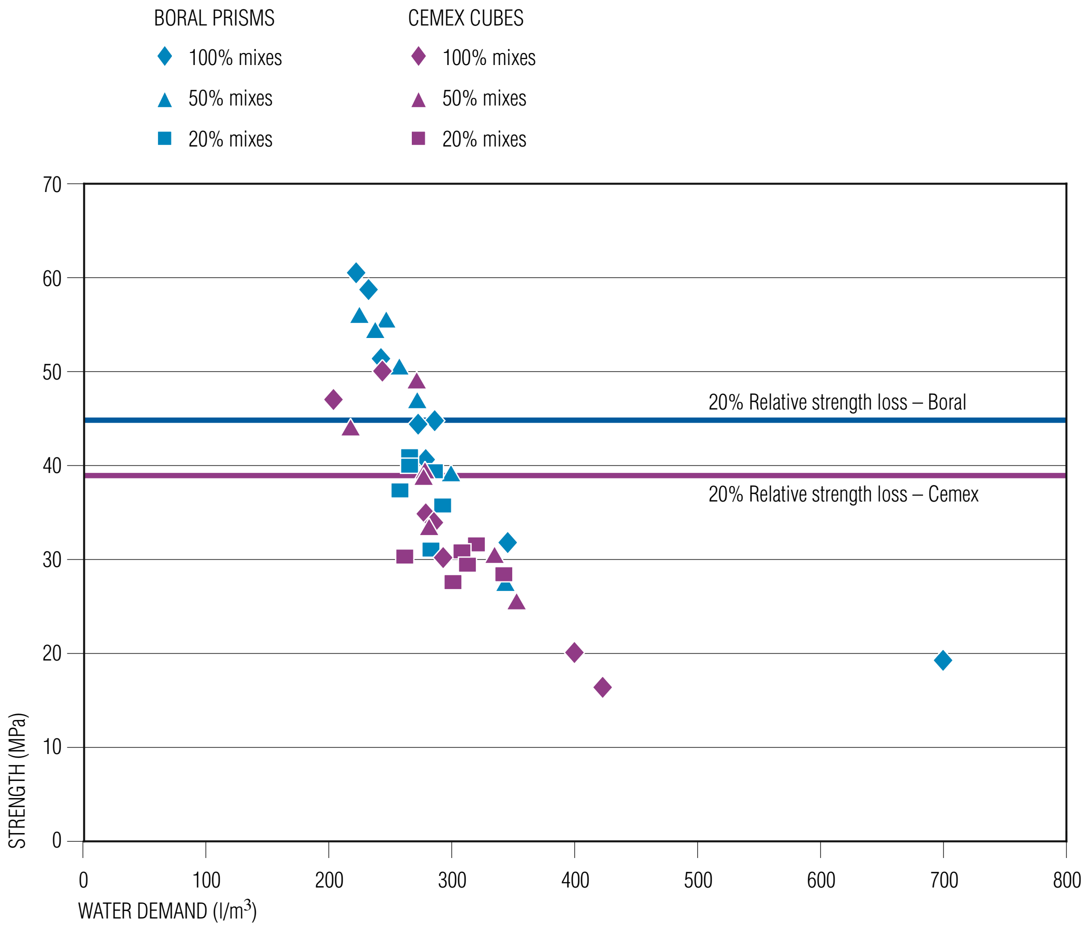


FIGURE 2.4 28-day strength results

In the Cemex data, for the 100% and 50% blends, the control sample and the D69 sample both produced results that were noticeably higher than the trend line for the strength versus water-cement ratio relationship, while the S51 sample recorded a lower strength. In the 20% blends both the S51 and the T68 samples recorded lower than expected results. There is no obvious explanation for the higher than expected results. Both S51 and T68 tested high for Micro Deval so it is feasable that the result may be reflecting the weaker particles of the two samples. However, this effect should not extend to mixes with only 20% of the manufactured sand. Sample S68 recorded the highest Micro Deval result, and yet the strength results follow the expected trend of increasing strength with lower water-cement ratio.

The strength data from both laboratories was plotted against the cement to water ratio where the cement content and water content of the mortar have been corrected for yeild **Figure 2.5**. Irrespective of the prism dimensions, most reported strengths fall within a band of 7.5 MPa either side of a linear trend (excluding the outliers), demonstrating that strength is controlled by water demand.

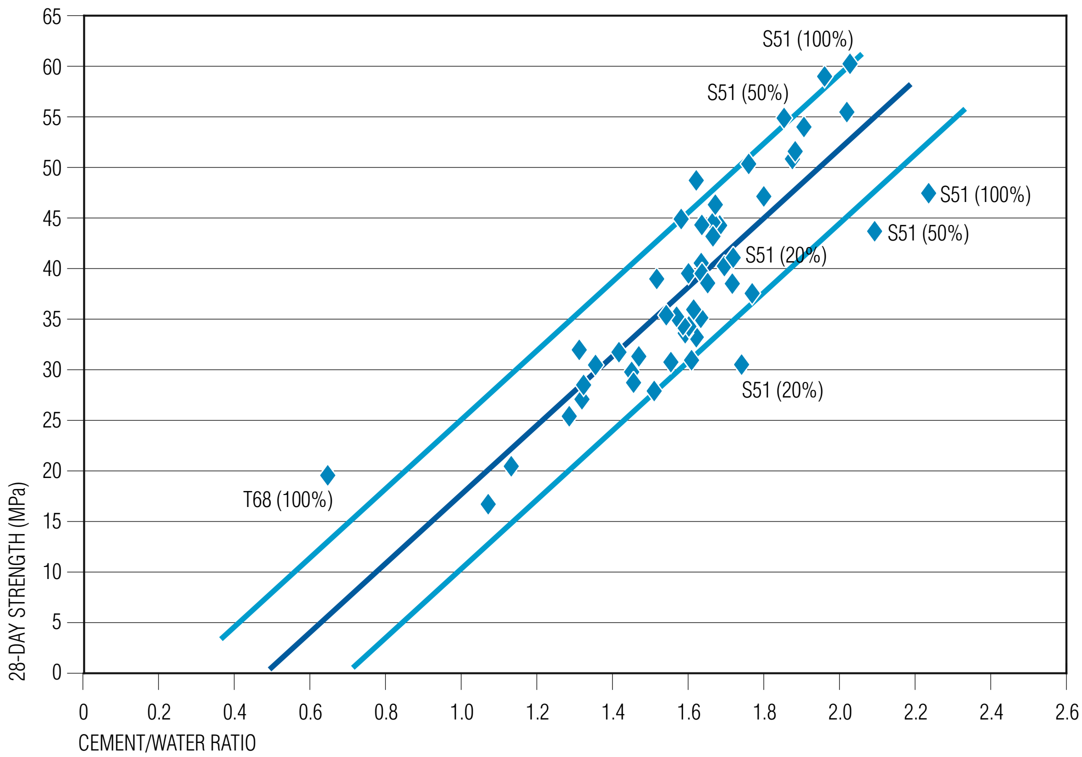


FIGURE 2.5 C/W v 28-day strength

Sample S51 appears to be particularly affected by differences in testing methods. All results for this sample that fall outside the band of results, and below the trend, were tested by Cemex, while the S51 samples that test above the expected range were tested by the Boral procedures.

The samples reporting low cement to water ratios and corresponding low strengths are those samples (T68 and S68) with more reactive mineralogy.

2.6.3 Mortar shrinkage

Shrinkage tests to AS 1012.13 for all mortar trials were conducted at Cemex's laboratory, while Boral's laboratory tested only the 100% manufactured sand mixes to AS 2350.13.

Comparison of the data for pairs of tests (result of the same material tested at both laboratories at the same age) revealed significant differences, with the Cemex data (that had the higher water demand) recording lower shrinkages. This relationship is the opposite of what may have been expected and is explained by the differences in specimen size. The data is shown in **Figure 2.6**.

The paper by Gilbert cited earlier identifies the relevance of specimen size in the determination of shrinkage. By applying the model formula proposed by Gilbert, a reasonable correlation was developed between the shrinkage recorded by the 40-mm square moulds at 28 days (Boral tests) compared with the 56-day shrinkages recorded on the 75-mm square moulds (Cemex tests). This relationship is demonstrated in **Figure 2.7** with a plot of uncorrected Cemex data at 56 days plotted against the comparable mortar tested by Boral at 28 days. The theoretical relationship from Gilbert's model calculated that the 56-day shrinkage should represent 94% of the 28-day shrinkage as a result of surface area to volume difference between the two moulds for shrinkage around 800 μm.

Accepting the model as a means of comparing the two sets of data, the Cemex data was factored by a constant of 1.06 to remove the influence of the larger prism size; this corrected data is also plotted in **Figure 2.7**.

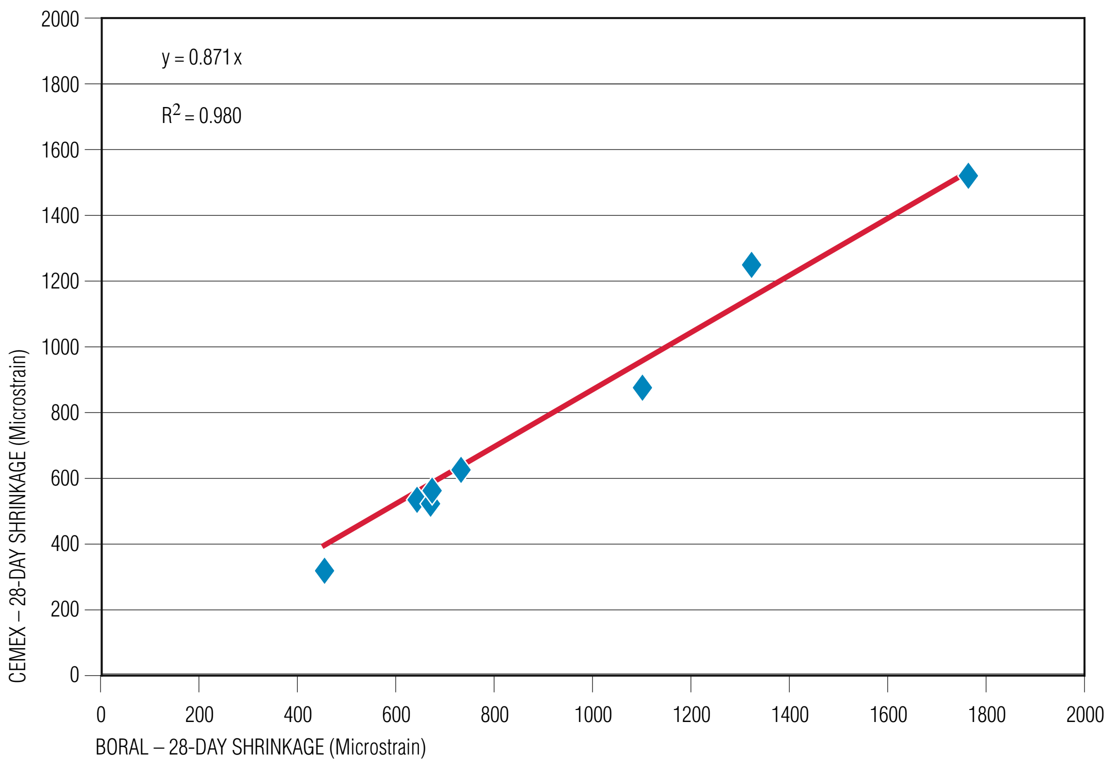


FIGURE 2.6 Shrinkage comparison (microstain)

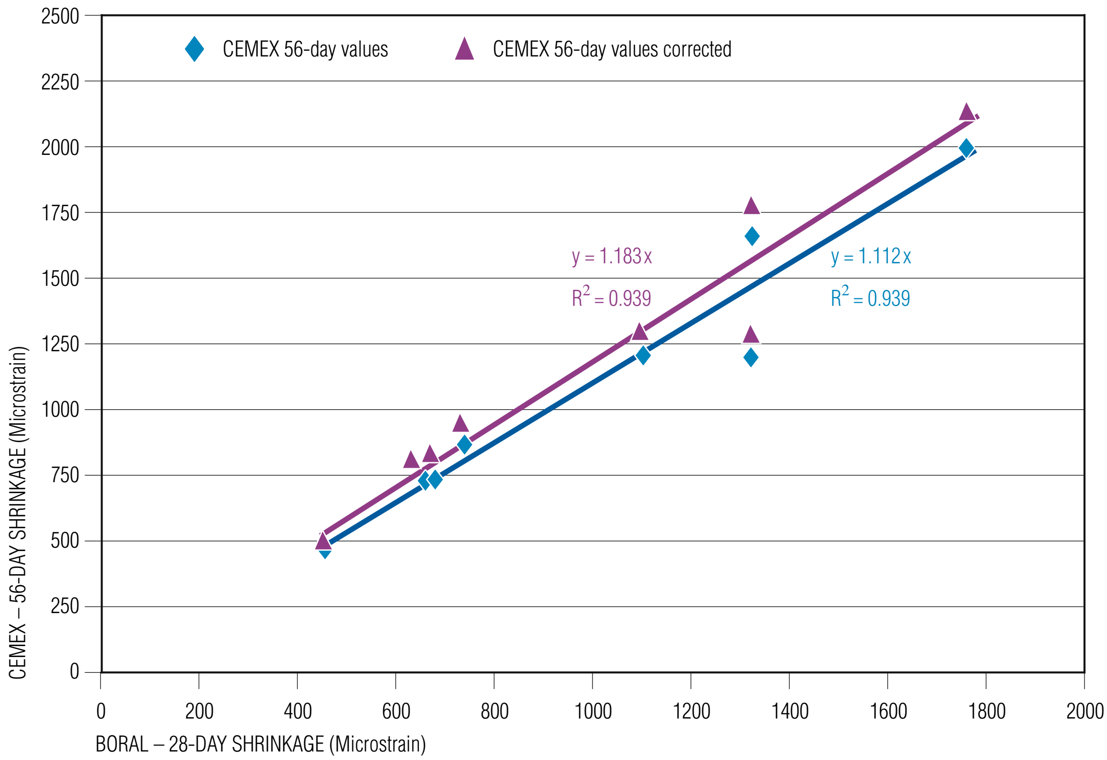


FIGURE 2.7 Shrinkage comparison (microstrain)

All the shrinkage results obtained by Cemex laboratory was 'corrected' for the size of the specimens and all shrinkage data was plotted against water demand. Most data fits within a band of shrinkage that can be predicted based on water demand, with a variation from prediction of less than 150 µm. Three samples in the 100% manufactured sand series of mixes (L24, S68 and T68) tested by both laboratories recorded shrinkage results between 400 and 900 µm above the strain predicted for shrinkage based solely on water demand. These three samples represent the samples with the highest microfines activity as measured by the multiple of MBV x 75 µm and, as may be expected, they have higher levels of adverse mineralogy (see **Table 2.1**). It might be expected that these reactive minerals would cause shrinkage beyond that resulting from the water demand of the mix.

The 20% mixes for samples G80 and S68 have shrinkage values less than that predicted by the relationship to the water demand. These two result are the extremes of a noted trend for the mixes with 80% Kurnell sand to record shrinkages less than that predicted for the water content of the mix. It is possible that the Kurnell sand, which is composed of mainly quartz grains that are single crystals, is better able to resist shrinkage, compared with the particles of the manufactured sands which are more likely to be broken rock fragments consisting of combined mineral grains. **Figure 2.8** illustrates this point; the shrinkage result for the 20% mixes are more likely to cluster below a line of best fit for the relationship between shrinkage and water demand.

Figure 2.9 shows that the shrinkage of the 100% and 50% mixes is dependent on water demand controlled by the grading and mineralogy of the fine aggregate. By the time that the mixes have reached 20% blends (80% Kurnell sand) there is little impact on shrinkage from the manufactured sand; shrinkage is substantially controlled by the properties of the single-sized, inert dune sand.

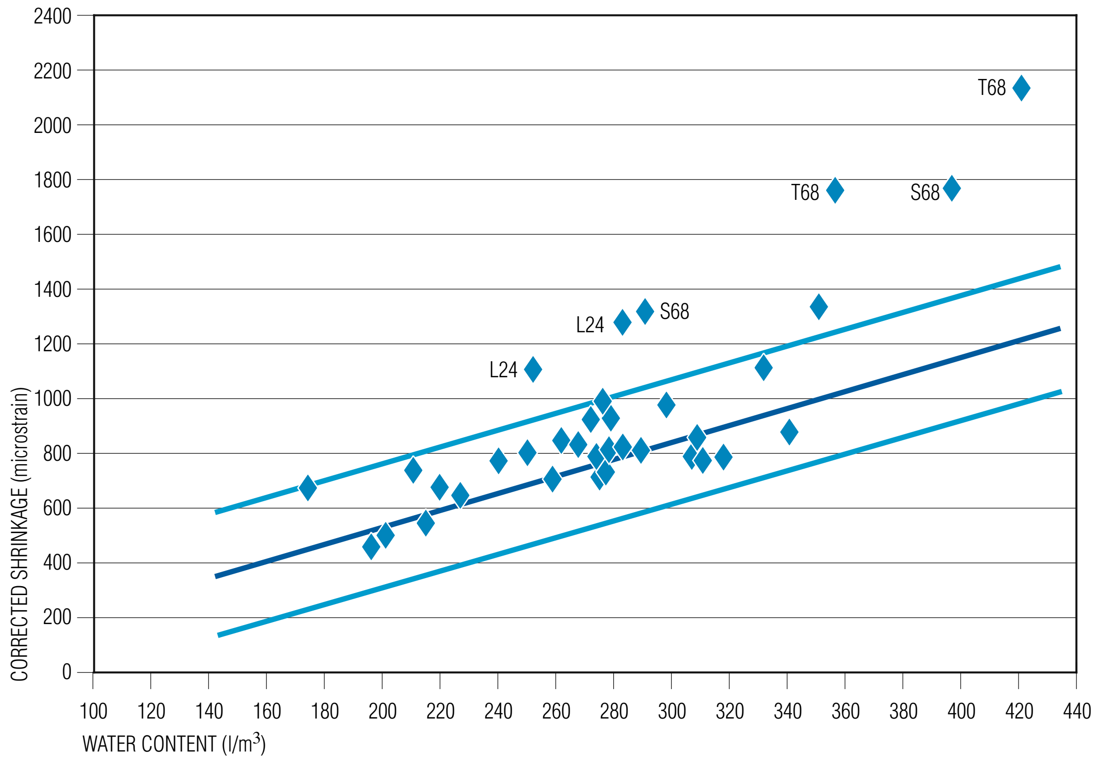


FIGURE 2.8 Corrected shrinkage v water content

FIGURE 2.9 Corrected shrinkage v water content

2.6.4 Bleeding

Bleeding of all mixes was measured at Cemex laboratory and the results compared with a series of factors to determine those properties of the manufactured sands most likely to affect concrete bleeding. Lack of adequete bleeding has been a cause of difficulty in using concretes with manufactured sands, particularly when concrete is placed in summer conditions.

Bleeding results for mortars cannot be transferred to concrete mixes because the presence and grading of the coarse aggregate has a significant effect on the bleeding of concrete. However, understanding the factors that influence bleeding in mortars allows for consideration of these factors in a concrete mix.

Bleeding results were compared with the voids content of the fine aggregate measured in the New Zealand Flow Cone test and this comparison is illustrated in **Figure 2.10**.

The figure illustrates that bleed is to some extent controlled by voids in the packed aggregate and, as would be expected, as the voids are reduced, bleed is reduced. However, the relationship is far from a good correlation as multiple bleed results are achieved at the same voids content. It is probable that not only the void content but the grading distribution plays a part. All mixes with higher proportions of Kurnell sand, the 50% and 20% mixes, tend to have higher bleed. This may be explained by the single-size nature of the Kurnell sand which will tend to prevent filling of pore spaces with finer particles and lead to the formation of an open aggregate skeleton.

Finally, **Figure 2.10** illustrates that the samples with the most active mineralogy are also those producing lowest bleeding. According to the mineralogical analysis (**Table 2.1**) sample L24 is dominant in swelling clay minerals and so it is no surprise that pore spaces in the 100% mix of this sample might be sealed. Neither sample T68 nor S68 have been analysed as containing high proportions of expansive clay, but the MBV value suggests that the fines are sufficiently active for the free passage of water to be prevented.

Although each of the factors mentioned might require consideration when evaluating the bleed of a concrete mix, **Figure 2.11** suggests that an initial assessment might be made simply from the quantity of microfines in the mix.

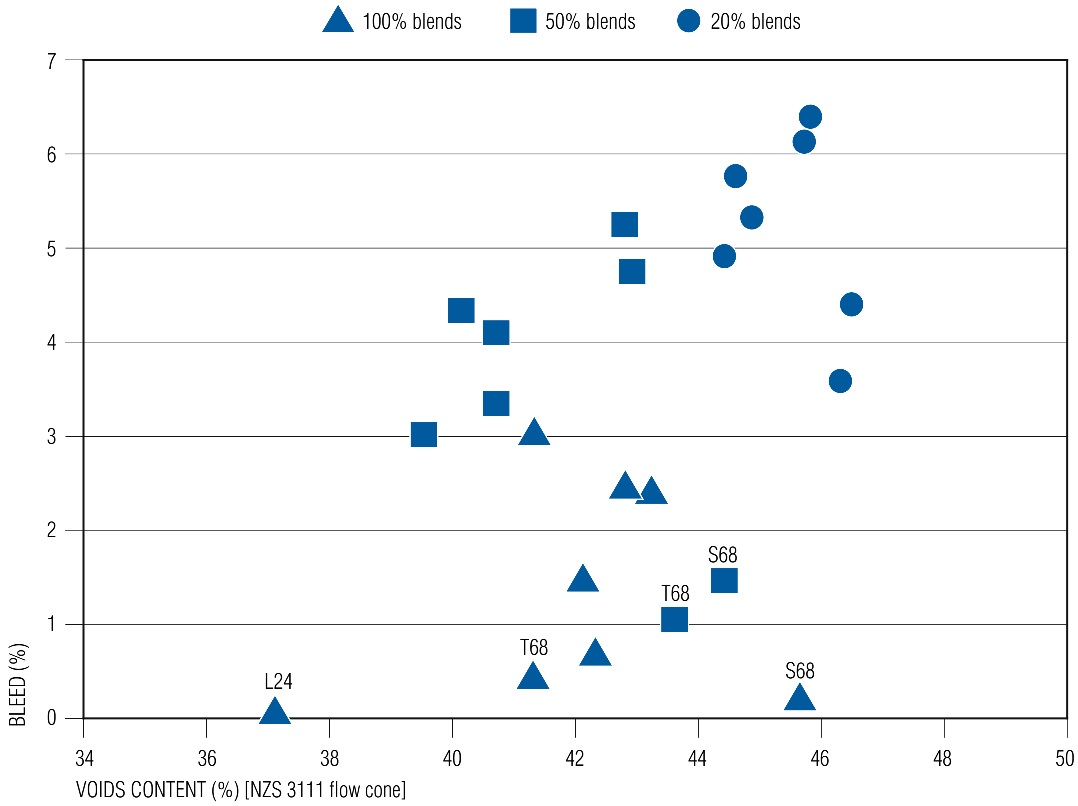


FIGURE 2.10 Correlation between voids and bleeding

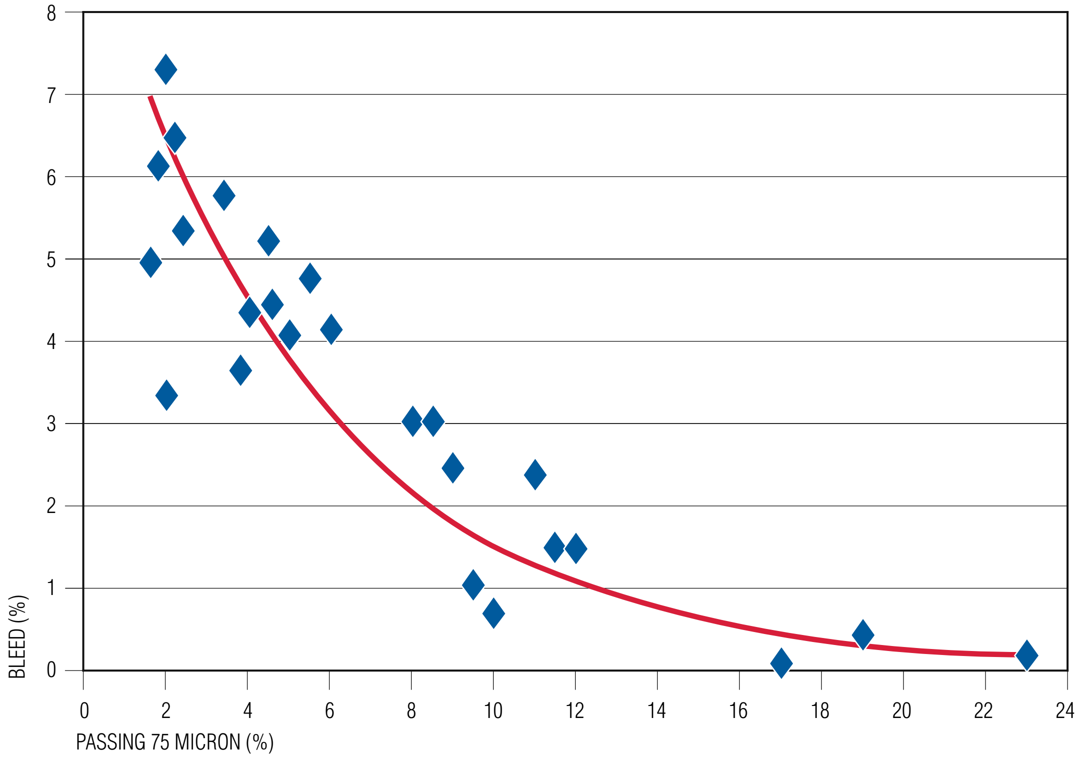


FIGURE 2. 11 Bleeding ratio v passing 75 µm (%) for all sand blends

2.6.5 Mix workability

The technical staff at Cemex recorded a series of observations on their ability to finish test specimens of the trial mortars. They also applied a ranking to each mix that identified which mixes were easy to work and which were more difficult. The control mix of Nepean sand blended with Kurnell was assigned a ranking of 5, with values between 4 and 1 considered harder to work while values 6 to 10 were increasingly easy to finish.

An attempt has been made to relate the ranking to the properties of the manufactured sand or to properties of the mix given in **Table 2.4**. As the data indicates, there are no strong relationships but some influences are apparent, at least for a number of mixes.

1. Higher levels of passing 75 µm material make the mix more difficult to finish unless the microfines contain higher levels of active material, in which case the mix becomes easier to finish.`
2. Sands with short flow times were more likely to be easier to finish, but usually only if the voids content was higher. More-workable mixes tend to be towards the lower right hand side of the acceptable envelope on the NZS 3111 chart. However, see point 5 below.
3. All but two mixes that consisted of 100% manufactured sand were assessed as gritty by the technicians and this was regardless of how coarse the particle size distribution as indicated by the material retained on the 2.36-mm sieve. This may indicate that the perception of the mix being gritty is related to the angularity of the grains and not necessarily to the top size of the grading. The two 100% mixes that were assessed as easy to finish contained high proportions of active microfines which provided additional 'lubrication' to the mix.
4. However, moderate to high levels of the multiple of MBV x passing 75 µm (up to about 200) were not associated with ease of finishing but were associated with the grittiness of the 100% mixes. It would appear that active fines in the samples tested in this research will not provide a finishing aid until they reach a level where they would become detrimental to the performance of the mix.
5. Ease of finish appeared to be related to increased water content in the mix, but this is considered a side effect of the higher level of voids associated with higher levels of Kurnell sand. In other words, the mixes became easier to work as the level of Kurnell sand increased and the water demand also increased. The improvement in workability probably has more to do with the rounded shape of the Kurnell sand rather than the increased water in the mix.

TABLE 2.4 Workability ranking

ID and (mix %)	Workability ranking	Passing 75 µm	NZS 3111 flow time	NZS 3111 voids	Grading + 2.36 mm	MBV x 75 µm	Water demand
G80 (100)	2	12.0	35.6	42.1	1	141.6	279
S51 (100)	3	8.0	27.9	41.3	22	9.6	201
L24 (100)	3	17.0	31.8	37.1	26	193.8	283
T68 (50)	3	8.5	21.9	43.6	0.7	104.2	351
L16 (100)	3.5	10.0	26.6	42.3	9	108.0	276
S51 (50)	4	5.0	22	40.1	11	3.5	215
D69 (100)	4	9.0	28.2	42.8	22	30.6	240
L24 (50)	4	4.5	22.2	39.5	13	26.2	272
T68 (20)	4	1.8	21	46.3	0.3	9.6	298
N53 (100)	4.5	11.0	31.2	43.2	3	132.0	290
S51 (20)	5	0.4	20.2	44.4	4	0.9	259
NRS (80)	5	1.2	22.8	40.7	4	3.1	269
D69 (50)	5	0.6	23	42.8	11	1.5	275
G80 (20)	5	0.2	20.5	44.9	0	1.4	318
S68 (100)	6	23.0	35.7	45.6	4	328.9	397
T68 (100)	6	19.0	25	41.3	1	463.6	397
G80 (50)	7	9.5	23	40.7	1	56.6	274
L24 (20)	7	3.8	20.1	44.6	5	9.5	283
D69 (20)	7	1.9	20.8	45.7	4	2.1	307
S68 (50)	7	1.0	26.5	44.4	2	7.3	332
N53 (50)	8	0.5	22.5	42.9	2	3.4	278
S68 (20)	8	0.2	21.7	46.5	1	1.3	341
N53 (20)	9	0.1	20.7	45.8	1	1.0	311

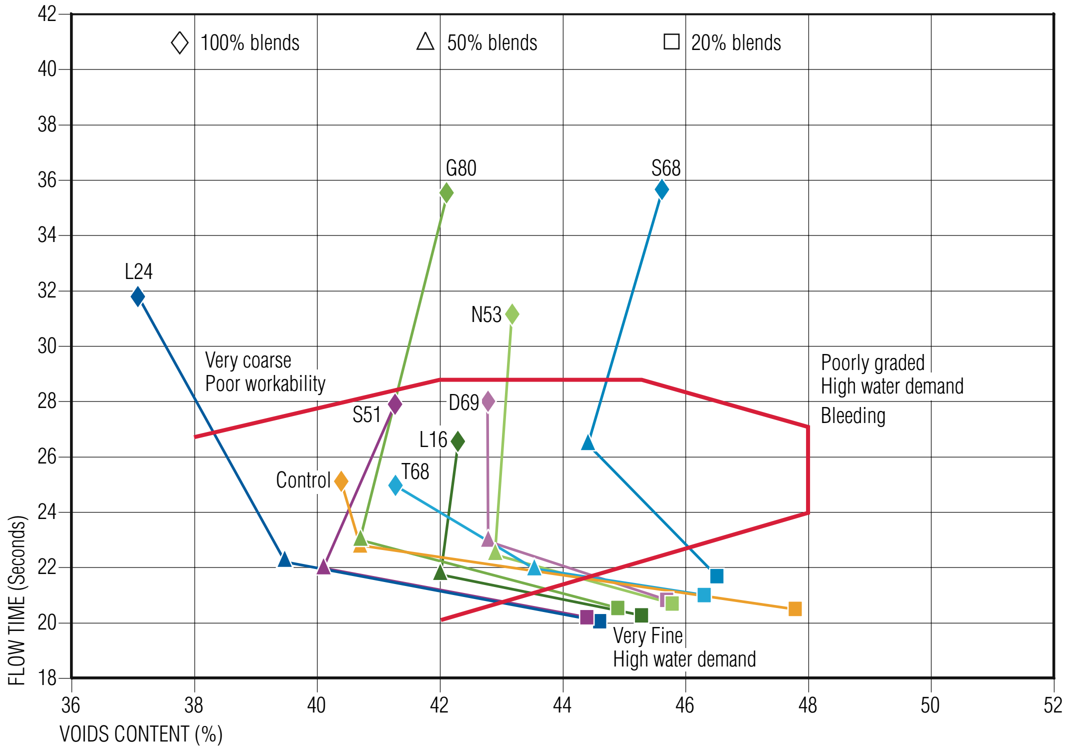
2.7 SAND BLENDS

The second objective of this part of the research was to determine the limits of specification for manufactured sands by testing and predicting the effect of the sands on the mortars. Limiting these effects to what could be tolerated (ie by establishing a lower limit of acceptance in the market) the critical limit for the mortar properties is established.

This research has shown that for the design properties under consideration, the mortar properties are controlled by the fine aggregate grading (influencing void content) the fine aggregate shape and surface friction (probably influencing voids and possibly workability) the quantity of material passing 75 µm, the microfines of the grading (influencing the bleed) and the activity of the microfines (influencing water demand, bleed, shrinkage and workability). In turn, water demand has a direct impact on mortar strength.

The concrete mix designer may not have much control over the materials used in a given geographic or economic region, and may therefore have limited ability to achieve an 'ideal' mix design. Nevertheless, it is the objective of this research to identify the properties of concern in the use of manufactured sand and to provide some guidance on how these concerns may be controlled.

It does not appear possible or desirable to fix limits on the voids content of manufactured sands or on fine aggregate produced by blending manufactured sands with natural sands. However, the limits suggested in NZS 3111 that were originally proposed for natural sands, have proved relevant to the results of this research (see **Figure 2.12**). It should be noted that in this project, the Flow cone was not used to determine a range of trial blends. Rather the blends were suggested by the range of current usage of the manufactured sands already in the market place. Three levels of mortars were prepared with the manufactured sand tested as 100% of the fine aggregate, in a 50% blend with Kurnell sand and in a 20% blend with Kurnell. These fine aggregate blends were tested using the flow cone; the plot shown in **Figure 2.12** illustrates that the test would have been useful in measuring the effect of blending on the voids content and therefore on predicting some of the impact on water demand. The test may point to some effects on workability and this could be useful information at a design stage. However, the test cannot provide any information on the effects of active microfines, although this research suggests that these effects are of equal or greater significance.



Each sample graph plots the three blends used in the research, with 100% manufactured sand at the top of the graph (higher flow time) the 50% blend within the acceptance band, and the 20% blend towards the lower right of the graph

FIGURE 2.12 NZS 3111 Flow cone results

To define the effect of the manufactured sand or manufactured sand blend on the properties of mortar mixes, and by extension to the properties of concrete incorporating these mortars, a series of tests on mixes using each manufactured sand at three different mix percentages was conducted at Cemex laboratory. The tests were conducted against a control of Nepean Sand with Kurnell sand. A similar mortar to the control has been a part of Sydney concrete for many years. As a very general statement, Sydney mixes have an acceptable to low level of shrinkage, have developed adequate strength, perhaps at the cost of having slightly too high a water demand which has in turn required slightly high cement contents. Sydney fine aggregates tend to be too 'clean', with very low levels of microfines in the aggregates, making the mixes likely to bleed too readily and causing minor workability issues. Note the comments on workability of the control mixes in this research that report the control mixes as being 'gritty' and difficult to close.

Based on the experience of Sydney concrete and by extension, the mortar used as control, the following criteria were adopted to define 'acceptable performance'. The trial mortars should:

- achieve a minimum strength of 80% of the control mortar;
- achieve shrinkage less than 120% of the control mortar;
- not require water beyond that used in the control.

Once the acceptance criteria were defined, it was possible to examine the results of the series of trials by plotting the blend mix percentages against the measured properties of the trials relative to the control.

Two example plots are reproduced in **Figures 2.13 and 2.14**, while all plots are included as **Appendix 3**.

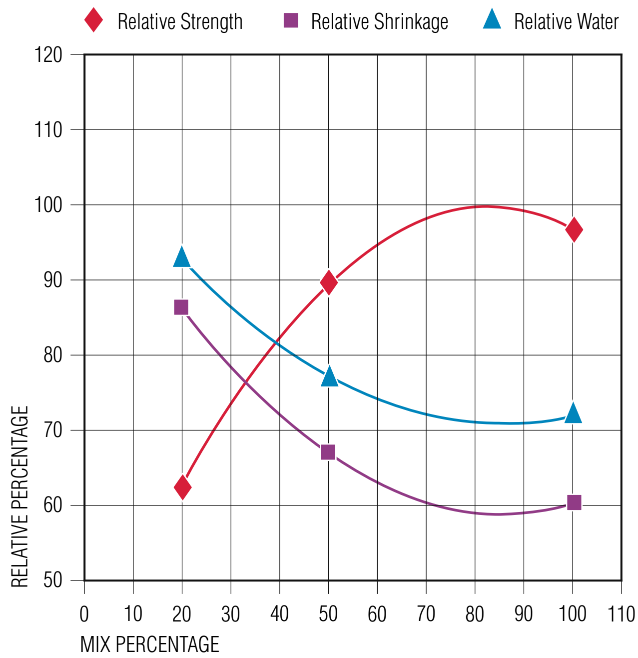


FIGURE 2.13 Mix design chart for Sample S51

The results of the trial are fitted using a second order polynomial curve fit; the acceptable mix ranges can be read from the relative percentage the trial achieved against the control. In the case of Sample S51 80% control strength can be achieved with any mix of S51 with Kurnell sand where the proportion of S51 is greater than 35% with no upper limit. Similarly, water demand less than 100% of control is achieved with any mix above 15% S51, while shrinkage less than 120% of control is achieved with any mix percentage of S51. Of note is that these mixes clearly reach an optimum when the percentage of S51 is at 85%. Here the mortar reaches maximum strength and minimum shrinkage at minimum water addition.

By contrast, **Figure 2.14** illustrates the T68 sample. In the first stage of the research, T68 was considered suspect and the mortar trials simply confirm that the material should be used in very low blend quantities. An additional complication with these types of materials is that the Kurnell sand may not have been the ideal blending sand for materials that can be used only in low quantities. Because of the single sized, fine nature of Kurnell sand, when used in high quantities it tends to significantly increase the void content of the aggregate, creating higher water demand, and this effect may dominate the analysis.

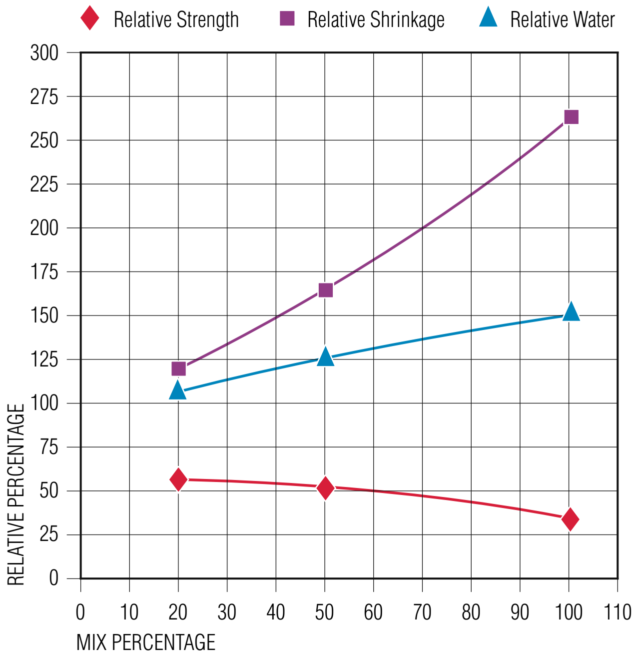


FIGURE 2.14 Mix design chart for Sample T68

However, with the T68 material, it is clear that the mix is not capable of achieving the strength criteria (although whether a 100% Kurnell mix will achieve only just above 50% of the control strength was never checked). Water demand with this material rises rapidly and shrinkage exceeds the criteria of 120% control at low mix additions and rises rapidy, pointing to serious concerns of cracking at low additions of T68. For this material, a maximum mix addition of 10% is recommended.

A similar analysis was conducted for each of the samples based on the graphs given in **Appendix 3**, and a summary of the conclusions is presented in **Table 2.5**.

Once the maximum recommended mix percentage has been determined, a limit can be assessed for the activity of the microfines that recognises the performance of the materials in mortar. As detailed earlier, the Methylene Blue value and the passing 75 µm data was not determined in this research but was drawn from earlier data. The value of the Multiple, Methylene Blue x 75 µm could be determined for any blend by proportioning.

TABLE 2.5 Recommended maximum percentage of manufactured sand tested

	Mix range				
Sample	Strength (%)	Shrinkage (%)	Water (%)	**Recommended max percentage**	**Comment**
D69	43–100	0–100	45–100	100	
S51	36–100	10–100	10–100	100	Ideal blend at 85% S51
L16	50–85	20–75	25–100	75	
N53	50–70	45–65	50–100	65	Reaches only 70% strength criteria
G80	50–80	20–80	45–100	65	This material used at 100%
L24	50–70	20–50	40–70	50	
S68	25–60	0–25	25–60	25	Does not meet strength criteria
T68	0–50	0–10	0–30	10	Does not meet strength criteria

Once these values were determined, a sensible limit of the Multiple for a blend of fine aggregate to be used in mortar was established at a value of 100. This value was then used to recalculate the mix proportions for all blends on the assumption that a blend was produced to the maximum of the recommended Multiple value. In only one case did this significantly alter the maximum recommended blend percentage. A mix using sample T68 could be blended with up to 21% of the material and still meet the criterion of a Multiple less than 100. Checking the performance curves, such an increase would increase mix shrinkage but it would be debatable if this increase would make the mix unacceptable. These calculations are summarised in **Table 2.6**.

A 'reality analysis' was established by comparing the recommended maximums with the blends being used by the Industry for these eight materials **Table 2.7**. This was a crude measure as the research was conducted with no knowledge of the actual mixes being used by industry. Information on the economic reasoning behind the blends was not available, and this factor alone probably explained why many of the mixes appear to be using less manufactured sand than the calculation might suggest was possible.

TABLE 2.6 Recalculated maximum percentage of manufactured sand

Sample	Recommended mix maximum percentage	Multiple MBV x pass 75 μm	Recalculated maximum with multiple = 100
D69	100	30.6	100
S51	100	9.6	100
L16	75	81.3	92.5
N53	65	86.1	75.6
G80	65	92.4	70.4
L24	50	97.4	51.3
S68	25	83	30.2
T68	10	47	21.4

TABLE 2.7 Comparison of current use of manufactured sand

Sample	**Industry normal use** (%)	**Industry maximum use** (%)	**Research recommended use** (%)
D69	40	100	100
S51	20	50	100
L16	30	40	75
N53	20	50	65
G80	100	100	65
L24	70	N/A	50
S68	12.5	25	25
T68	12.5	18.75	10*

* *This material is reported to be used in proportions as high as 75% in shotcrete.*

Although not by any means exact, the calculations give recommended blend proportions of a similar order to those being used. The differences may be the result of the influences of the coarse aggregate and the mix design in general.

The research also examined bleeding of the mortar. Bleeding of the control mixes was 3.3% and, as has been noted, bleeding of Sydney concrete mixes was sometimes considered high. It is of course difficult to determine bleeding of concrete from mortar as bleeding can be adjusted by the grading of the coarse aggregate. However, for this research, if an acceptable bleeding of between 1.5 and 2% is adopted, then for these mixes, the passing 75 µm of the fine aggregate should be limited to between 8 and 10%.

For most of the blends under consideration, if blended at the level recommended, the passing 75 µm would be less than 8%. If, however, blends were adjusted to allow for the maximum manufactured sand while conforming to the suggested limit of 100 for the Multiple of MBV x 75 µm, then a number of mixes would approach 10% passing 75 µm. The data is given in **Table 2.8**.

Until better information is available it would be advisable that the bleed of concrete mixes be confirmed as suitable for purpose for all situations where the fine aggregate blend passing 75 µm exceeded a value of 8%.

TABLE 2.8 Analysis of passing 75 µm in blends

Sample	Passing 75 µm in recommended blends (%)	Passing 75 µm in blends adjusted to multiple L = 100
D69	9	9
S51	8	8
L16	7.6	9.3
N53	7.5	8.4
G80	8	8.6
L24	8.8	9.0
S68	6.1	7.3
T68	2.4	4.5

2.8 CONCLUSIONS

Considering that this research involved only a limited number of trials, the following conclusions are tentative and require continuing Industry experience to refine and confirm the information generated in this project. However, there appears sufficient data to suggest the following:

- Compared to the use of natural sands that are typically rounded to sub rounded and partially smooth in surface texture, manufactured sands are typically angular and rough. Manufactured sands will have a higher proportion of microfines compared with a typical natural sand or natural sand blend. These two factors, taken together, mean that most manufactured sands will have a higher water demand compared to natural sand, with predictable consequences for mix design.
- Within this project, water demand was controlled by two significant factors. The voids content of the fine aggregate blend was the dominant factor for mixes with high proportions of Kurnell sand and a significant factor for mixes with 50% Kurnell sand. For mixes with 50% or more of manufactured sand the quantity and quality of the microfines became dominant in controlling water demand.
- This research confirmed that the mix design properties examined in this project are almost totally controlled by water demand.
- Within the constraints of the proposed use of the concrete, and the availability of suitable blending materials, mix designs should endeavour to minimise

voids, while still delivering a fit-for-purpose mix, as an effective means of reducing water demand.

- For mixes where water demand had not become excessive as a result of high voids content, trial blends in this project did not develop excessive water demand as a result of mineralogy, provided that the multiple of MBV x passing 75 µm did not exceed a value of 100 for the total fine aggregate. The first stage of the project had limited the multiple to a value of 150 for individual components of a blend with a proviso for using materials up to 200 with further investigation. If this latter recommendation were adopted, two samples in this research would have been eliminated from use. This research confirms only that samples S68 and T68 are usable in low blend levels, but there still may be justification for examining the use of more-reactive materials.
- The mineralogical data indicates that illite-rich manufactured sands may have limited application, as do those mineral sands limited because of the presence of smectite clays. At least for these samples, the MBV x 75 µm multiple appears as effective as X-ray diffraction in identifying potential issues. This finding may also confirm the use of the Sand Equivalent test as a screening tool as it is sensitive to the presence of illite.
- Mix bleed correlates with the level of passing 75 µm material (microfines) but there is also evidence that active microfines are more likely to minimise bleed. Once again, use of the MBV x 75 µm multiple should be effective in controlling microfines at an activity that delivers acceptable bleed. However, it is recommended that the bleed of concrete be confirmed as suitable-for-purpose for all mixes where the passing 75 µm of the fine aggregate blend exceeds 8%.
- For the mortar properties evaluated in this project, there did not appear to be any relationship to sodium sulphate loss or to degradation factor (fines). However, these properties are more likely to be associated with the long-term durability of concrete and none of the mortar tests conducted here address long-term performance.
- The testing conducted has confirmed that some manufactured sand is potentially suitable for use as the fine aggregate component of concrete without blending. However, most of the samples tested would be used in blends and procedures have been detailed for estimating the most suitable blend for each of the samples. This research was based on blending with Kurnell sand and it may be possible that higher percentages of the samples might be achieved with a different blending sand that reduced mix voids where that was acceptable for the use of the concrete. The procedures discussed in the research would still be applicable in determining these different blend proportions.
- However, data collected in the project suggests that perceptions of difficult workability may be related to the particle shape and surface texture of the manufactured sand. Inclusion of a rounded, smooth natural sand may be a useful workability aid for concretes using manufactured sands. Design of mixes for workability as opposed to the strength and shrinkage criteria used here may result in differing mix proportions.
- It is still felt that the proposed limitations on active mineralogy and bleed would apply irrespective of the design criteria (strength, shrinkage or workability) of the mix.

Appendix 1

METHOD OF TEST FOR MANUFACTURED SAND FOR USE IN CONCRETE
The determination of relative water requirement, relative strength and relative drying shrinkage

Preface

This method was initially prepared by Tony Thomas (Boral Concrete) and Ross Anderson (Sunstate Cement) to provide a means of comparing the performance of manufactured sand in relation to standard sand specified in AS 2350.12. For the purpose of this project the method has been amended in two areas:

- The standard sand has been replaced with a control sand; a 'grey concrete sand' supplied from Kurnell.
- Sands are tested in SSD condition (not oven dry condition).

Method

1 SCOPE

This method sets out the procedure for determining the relative water requirement, the relative strength and relative drying shrinkage of a manufactured sand. All properties are determined by comparing results for a test sample mortar with results for a mortar using a control sand. This method uses equipment and procedures based on current cement and masonry standards.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard.

AS 1141.5	Methods for sampling and testing aggregates. Method 5: Particle density and water absorption of fine aggregates.
AS 1152	Test sieves
AS 2350	Methods of testing portland and blended cements
AS 2350.11	Method 11: Compressive strength of portland and blended cements
AS 2350.12	Method 12: Preparation of a standard mortar and moulding of specimens
AS 2350.13	Method 13: Determination of drying shrinkage of portland and blended cement mortars
AS 2701	Methods of sampling and testing mortar for masonry constructions
AS 2701.3	Method 3: Method for preparation of fresh mortar for testing
AS 2701.7	Method 7: Method for determination of water retention
AS 3853.6	Methods of test for supplementary cementitious materials for use with portland cement – Method 6: Determination of relative water requirement and relative strength
AS 3972	Portland and blended cements

3 DEFINITIONS

For the purpose of this project the definitions given below apply:

3.1 Control mortar

A mortar prepared using a General purpose portland cement and grey concrete sand supplied from Kurnell.

3.2 Test mortar

A mortar prepared using a mixture of the test sand and the cement used for the control mortar.

3.3 Test sand

A sample of manufactured sand that is prepared to SSD condition, and if not tested immediately it should be maintained in a sealed container until the time of testing.

4 PRINCIPLE

4.1 Relative water requirement

A control mortar is prepared using the amount of water required to give a specified flow. A test mortar having the same flow is prepared and the relative water requirement is calculated from the ratio of the water additions for the respective mixes.

4.2 Relative strength

Compressive strength determinations are performed on prismatic specimens made from control and test mortars prepared in the same manner as for the determination of the relative water requirement.

The relative strength of the test sample is calculated by expressing the test mortar strength as a percentage of the control mortar strength at both 7 days curing and at 28 days curing.

5 APPARATUS

The following apparatus is required:

1 All apparatus as specified in AS 2350.11.

2 Flow table, callipers and tamping rod, as specified in AS 2701.7.

6 MATERIALS

Water as specified in AS 2350.11. Cement shall comply with AS 3972 requirements for Type GP General Purpose portland cement. Portions of the same sample of cement shall be used for control and test mortars. The test sand will be prepared as per Section 3.3 above.

7 PREPARATION

7.1 General

In the determination of relative water requirement, relative strength and relative shrinkage results for the test mortar are related to results for the control mortar. It is therefore necessary to prepare a control mortar on each day that one or more test mortars are prepared.

7.2 Control mortar

A batch of control mortar shall consist of 450 ± 2 g of cement, 1350 ± 2 g of sand and sufficient water to achieve a flow of 110 ± 3% when determined in accordance with AS 2701.7 (nominally 225 g water but will vary with materials).

7.3 Test mortar

A batch of test mortar shall consist of 450 ± 2 g of the same cement as used for the Control Mortar, a quantity of test sand equal to 'St' ± 2 g and sufficient water to achieve a flow of 110 ± 3% when determined in accordance with AS 2701.7. The value of 'St' is calculated from the following formula:

$$St = \frac{\text{SSD particle density of test sand}}{\text{SSD particle density of standard sand}} \times 1350$$

The SSD Particle density of both sands should be tested in accordance with AS 1141.5.

7.4 Relative strength test specimens

Two sets of test specimens shall be prepared, one from a control mortar batch and the other from a test mortar batch. Fresh batches of mortar shall be prepared, that is, batches containing the quantities of water used to achieve the required flow as recorded in the procedure clauses of this Standard.

7.5 Relative drying shrinkage test specimens

Two sets of test specimens shall be prepared, one from a control mortar batch and the other from a test mortar batch. Fresh batches of mortar shall be prepared, that is, batches containing the quantities of water used to achieve the required flow as recorded in the procedure clauses of this Standard.

8 PROCEDURE

8.1 General

Materials and apparatus

8.2 Control mortar

The procedure shall be as follows:

(a) Mix the batch of mortar as described in AS 2350.12 with the following variation from method:

- Pour water into the bowl and with the mixer in operating position, add the cement into the middle of the bowl.
- Immediately after adding the cement, start the mixer on low speed to 30 s. Stop the mixer and add the sand to 30 s. Switch the mixer on to low for 30 s and then onto high for 30 s.
- Stop the mixer for 90 s, during the first 15 s, remove by means of a scraper (See AS 2350.12 Clause 4.3.2) all mortar adhering to the wall and bottom part of the bowl, and place in the middle of the bowl.
- Mix on high for a further 60 s and rest for 8 minutes. During this rest the bowl should be left in operating position, the bowl and mixer paddle being covered to avoid loss of moisture.
- Finish mixing on high for 60 s.

Timing of each of the above mixing stages should be adhered to within 2 s. Record the time of start (cement addition) and time of finish of the mix cycle.

(b) Measure the flow of the mortar as described in AS 2701.7. If the flow is not within the range 110 ± 3%, the mortar shall be discarded and a new batch prepared with an adjusted water content.

(c) Provided the flow is in the range 110 ± 3%, record the mass of water used and the flow.

(d) Examine the flow sample and note the workability and any tendency to segregate (use a steel spatular to assist this examination).

8.3 Test mortar

The procedure shall be as follows:

(a) Mix the batch of mortar as described in Section 8.2 above.

(b) Measure the flow of the mortar as described in AS 2701.7. If the flow is not within the range of 110 ± 3%, the mortar shall be discarded and a new batch prepared with an adjusted water content.

(c) Provided the flow is within this range, record the mass of water used and the flow.

(d) Examine the flow sample and note the workability and any tendency to segregate in comparison to that of the mortar produced from the standard sand (use a steel spatular to assist this examination).

8.4 Relative strength specimens

The procedure shall be as follows:

(a) Prepare and cure each set of three specimens from a mortar batch as described in AS 2350.11. Note that three specimens are required for each test age.

(b) Demould the set of specimens as described in AS 2350.11.

(c) For a standard test, cure the specimens in water at 23 ± 2°C, as described in AS 2350.11, before testing at an age of 7 days with another set cast and cured in the same manner for testing at an age of 28 days.

NOTE: Specimens from both the control mortar and test mortar should be subjected to the same curing regime.

8.5 Compressive strength testing

The procedure shall be as follows:

(a) Determine the compressive strength of a set of specimens as described in AS 2350.11.

(b) Record the mean compressive strength for each set of specimens.

9 CALCULATION

9.1 Relative water requirement

The relative water requirement is calculated as follows:

$$\text{Relative water requirement} = \frac{m_t}{m_c} \times 100$$

where

m_t = mass of water used in test mortar, in grams
m_c = mass of water used in control mortar, in grams.

9.2 Relative strength

The following calculations shall be made:

(a) The relative strength at 7 days (R_7) is calculated as follows:

$$\text{Relative strength } (R_7) = \frac{T_7}{C_7} \times 100\%$$

where

T_7 = mean compressive strength of test mortar at 7 days, in MPa
C_7 = mean compressive strength of control mortar at 7 days, in MPa.

(b) The relative strength at 28 days (R_{28}) is calculated as follows:

$$\text{Relative strength } (R_{28}) = \frac{T_{28}}{C_{28}} \times 100\%$$

where

T_{28} = mean compressive strength of test mortar at 28 days, in MPa
C_{28} = mean compressive strength of control mortar at 28 days, in MPa.

9.3 Relative drying shrinkage

The following calculations shall be made:

(a) The relative drying shrinkage at 28 days (X_{28}) is calculated as follows:

$$\text{Relative drying shrinkage } (X_{28}) = \frac{XT_{28}}{XC_{28}} \times 100\%$$

where

XT_{28} = mean drying shrinkage of test mortar at 28 days, in microstrain (to nearest 10 microstrain)
XC_{28} = mean drying shrinkage of control mortar at 28 days, in microstrain (to nearest 10 microstrain).

10 RECORDS

The following records shall be kept:

(**a**) Identification of sample.

(**b**) Source and type of portland cement used in control mortar.

(**c**) Any variations from the prescribed procedure.

(**d**) Result of the calculation of each relative quantity expressed as a percentage to the nearest whole number.

(**e**) Time of start and finish of mixing (secs).

(**f**) Density of control and test sand (Round to 10 kg/m^3).

(**g**) Mass of each material used in the mix (gm).

(**h**) Any information required by AS 2350.11, 12, 13 and AS 2701.7.

(**i**) Particularly observe and record the observed workability and tendency to segregate of the test mortar by visual assessment following the flow test described in 8.3 above.

11 REPORT

The report shall include the following details:

(**a**) Identification of sample.

(**b**) Source and type of portland cement used in control mortar.

(**c**) Any variations from the prescribed procedure.

(**d**) Result of the calculation of each relative quantity expressed as a percentage to the nearest whole number.

(**e**) Relevant information as per 10 (i) above.

EIGHT-SAMPLE PROPERTY SUMMARY including CEMEX mortar results

PROPERTY	Control sample 80% Kur: 20% Nep	1 Sample D69 average	2 Sample G80 average	3 Sample L16 average	4 Sample L24 average	5 Sample N53 average	6 Sample S51 average	7 Sample S68 average	8 Sample T68 average
Grading sieve (mm) 6.7		100	100	100	100	100	100	100	100
Grading sieve (mm) 4.75		100	99	99	97	95	99	100	98
Grading sieve (mm) 2.36		78	69	91	74	74	78	96	85
Grading sieve (mm) 1.18		45	44	55	49	53	38	65	73
Grading sieve (mm) 0.600		29	27	35	34	37	21	47	60
Grading sieve (mm) 0.425		23	24	28	29	31	16	40	49
Grading sieve (mm) 0.300		19	21	23	26	25	13	35	37
Grading sieve (mm) 0.150		13	16	15	21	16	10	28	25
Grading sieve (mm) 0.075		9	12	10	17	11	8	23	19
AS 1141.33 Clay and silt content		13	31	22	33	22	13	48	19
AS 1141.12 <75um		8.15	10.3	9.9	15.4	9.5	7.4	22.2	17.2
AS 1141.13 <2um		1.4	2.3	2.8	0.7	1.7	0.5	4.4	4.8
Degradation factor fine		85	86	88	84	90	89	74	53
Sand equivalent		74	66	76	60	70	81	40	25
SSD density	2.58 dry	2.67	2.63	2.67	2.64	2.61	2.67	2.64	2.48
Water absorption		0.9	2.1	2.3	3.3	0.9	0.8	1.7	3.6
Sodium sulphate soundness		0.5	0.7	1.4	1.1	0.7	0.2	1.3	6
–4.75 mm voids content (%)40.7		42.8	42.1	42.3	37.1	43.2	41.3	45.6	41.4
–4.75 mm flow time (sec) 22.8		28.5	35.6	26.6	31.8	31.2	27.9	36.1	25.2
–4.75 mm +75 µm voids content (%)		44.7	45.1	45.8	44.6	43.9	43.6	47.7	45.0
–4.75 mm +75µm flow time (sec)		29.9	38.2	27.6	41.8	36.6	28.7	30.4	25.3
–2.36 mm voids content (%)		44.0	43.2	41.8	38.8	45.4	42.2	44.7	42.2
–2.36 mm flow time (sec)		27.9	26.5	23.6	24.4	25.7	26.6	37.2	22.8
–2.36 mm +75 um voids content (%)		46.6	47.5	47.2	48.1	47.3	44.6	48.4	47.7
–2.36 mm +75 um flow time (sec)		26.1	26.8	26.2	27.1	24.9	26.3	28.7	23.3
7 d Mortar cubes control – 80% Kurnell:20% Nep	38.5	–	–	–	–	–	–	–	–
7 d Mortar cubes 100%	–	40.7	30.3	28.2	27.7	28	43.5	15.7	13.7
7 d Mortar cubes 50%	–	35	33	30.3	28.8	29.5	38.3	24.7	20.3
7 d Mortar cubes 20%	–	25.3	26.2	24.3	31.3	25.3	25.3	24	24.7
28 d Mortar cubes control – 80% Kurnell:20% Nep	48.8	–	–	–	–	–	–	–	–
28 d Mortar cubes 100%	–	50.8	34.3	35.2	34.7	30.7	47.3	20.3	16.7
28 d Mortar cubes 50%	–	44.5	39	38.7	38.5	33.2	43.8	30.5	25.5
28 d Mortar cubes 20%	–	31.2	31.8	28.7	33.7	29.7	30.5	28.7	27.7

continues

EIGHT-SAMPLE PROPERTY SUMMARY including CEMEX mortar results *continued*

PROPERTY		Control sample 80% Kur: 20% Nep	1 Sample D69 average	2 Sample G80 average	3 Sample L16 average	4 Sample L24 average	5 Sample N53 average	6 Sample S51 average	7 Sample S68 average	8 Sample T68 average
Density 7 days control – 80% Kurnell:20% Nep		2287	–	–	–	–	–	–	–	–
Density 7 days	100%	–	2340	2227	2247	2267	2260	2327	2140	2047
Density 7 days	50%	–	2173	2220	2220	2207	2227	2193	2220	2100
Density 7 days	20%	–	2267	2147	2160	2260	2180	2113	2213	2127
Density 28 days control – 80% Kurnell:20% Nep		2320	–	–	–	–	–	–	–	–
Density 28 days	100%	–	2367	2227	2207	2247	2193	2280	2093	1987
Density 28 days	50%	–	2200	2207	2127	2227	2173	2180	2133	2073
Density 28 days	20%	–	2167	2140	2073	2180	2133	2040	2120	2167
Shrinkage 56 days control – 80% Kurnell:20% Nep		760	–	–	–	–	–	–	–	–
Shrinkage 56 days	100%	–	720	870	920	1200	760	460	1660	2000
Shrinkage 56 days	50%	–	670	740	790	860	690	510	1040	1250
Shrinkage 56 days	20%	–	740	730	800	770	720	660	820	910
W/C ratio control – 80% Kurnell:20% Nep		0.617	–	–	–	–	–	–	–	–
W/C ratio	100%	–	0.534	0.619	0.614	0.628	0.646	0.446	0.882	0.936
W/C ratio	50%	–	0.611	0.609	0.583	0.605	0.617	0.478	0.737	0.78
W/C Ratio	20%	–	0.683	0.707	0.687	0.628	0.692	0.575	0.759	0.661
Flow table control – 80% Kurnell:20% Nep		208	–	–	–	–	–	–	–	–
Flow table	100%	–	210	212	213	207	212	210	209	207
Flow table	50%	–	212	213	207	209	207	209	211	210
Flow table	20%	–	207	210	209	208	212	207	209	212
Water control – 80% Kurnell:20% Nep		278	–	–	–	–	–	–	–	–
Water	100%	–	240	279	276	283	290	201	397	421
Water	50%	–	275	274	262	272	278	215	332	351
Water	20%	–	307	318	309	283	311	259	341	298
Workability control – 80% Kurnell:20% Nep		5	–	–	–	–	–	–	–	–
Workability 0 to 10	100%	–	4	2	3 to 4	3	4 to 5	3	6	6
Workability 0 to 10	50%	–	5	7	8 to 9	4	8	4	7	3
Workability 0 to 10	20%	–	7	5	8	7	9	5	8	4

continues

EIGHT-SAMPLE PROPERTY SUMMARY including CEMEX mortar results *continued*

PROPERTY		Control sample 80% Kur: 20% Nep	1 Sample D69 a	2 Sample G80	3 Sample L16	4 Sample L24	5 Sample N53	6 Sample S51	7 Sample S68	8 Sample T68
Ratio bleed:mix water control – 80% Kurnell:20% Nep		3.33	–	–	–	–	–	–	–	–
Ratio bleed:mix water	100%	–	2.46	1.46	0.69	0.07	2.39	3.02	0.19	0.4
Ratio bleed:mix water	50%	–	5.23	4.13	4.07	3.01	4.75	4.33	1.48	1.05
Ratio bleed:mix water	20%	–	6.14	5.34	7.29	5.78	6.48	4.96	4.43	3.63
Diff in setting time (mins) control – 80% Kurnell:20% Nep		115	–	–	–	–	–	–	–	–
Diff in setting time (mins)	100%	–	120	105	135	125	135	105	150	190
Diff in setting time (mins)	50%	–	130	100	110	140	125	80	130	130
Diff in setting time (mins)	20%	–	110	105	145	130	145	130	130	125
Diff in water from control	100%	nil	–38	1	–2	5	12	–77	119	143
Diff in water from control	50%	nil	–3	–4	–16	–6	0	–63	54	73
Diff in water from control	20%	nil	29	40	31	5	33	–19	63	20

EIGHT-SAMPLE PROPERTY SUMMARY including BORAL mortar results

		1	2	3	4	5	6	7	8
PROPERTY	**Control sample** 80% Kur: 20% Nep	**Sample D69 average**	**Sample G80 average**	**Sample L16 average**	**Sample L24 average**	**Sample N53 average**	**Sample S51 average**	**Sample S68 average**	**Sample T68 average**
Grading sieve (mm) 6.7		100	100	100	100	100	100	100	100
Grading sieve (mm) 4.75		100	99	99	97	95	99	100	98
Grading sieve (mm) 2.36		78	69	91	74	74	78	96	85
Grading sieve (mm) 1.18		45	44	55	49	53	38	65	73
Grading sieve (mm) 0.600		29	27	35	34	37	21	47	60
Grading sieve (mm) 0.425		23	24	28	29	31	16	40	49
Grading sieve (mm) 0.300		19	21	23	26	25	13	35	37
Grading sieve (mm) 0.150		13	16	15	21	16	10	28	25
Grading sieve (mm) 0.075		9	12	10	17	11	8	23	19
AS 1141.33 Clay and silt content		13	31	22	33	22	13	48	19
AS 1141.12 <75um		8.15	10.3	9.9	15.4	9.5	7.4	22.2	17.2
AS 1141.13 <2um		1.4	2.3	2.8	0.7	1.7	0.5	4.4	4.8
Degradation factor fine		85	86	88	84	90	89	74	53
Sand equivalent		74	66	76	60	70	81	40	25
SSD density	2.64	2.67	2.63	2.67	2.64	2.61	2.67	2.64	2.48
Water absorption	1	0.9	2.1	2.3	3.3	0.9	0.8	1.7	3.6
Sodium sulphate soundness		0.5	0.7	1.4	1.1	0.7	0.2	1.3	6
–4.75 mm voids content (%)40.7	40.7	42.8	42.1	42.3	37.1	43.2	41.3	45.6	41.4
–4.75 mm flow time (sec) 22.8	22.8	28.5	35.6	26.6	31.8	31.2	27.9	36.1	25.2
–4.75 mm +75 µm voids content (%)		44.7	45.1	45.8	44.6	43.9	43.6	47.7	45.0
–4.75 mm +75µm flow time (sec)		29.9	38.2	27.6	41.8	36.6	28.7	30.4	25.3
–2.36 mm voids content (%)		44.0	43.2	41.8	38.8	45.4	42.2	44.7	42.2
–2.36 mm flow time (sec)		27.9	26.5	23.6	24.4	25.7	26.6	37.2	22.8
–2.36 mm +75 um voids content (%)		46.6	47.5	47.2	48.1	47.3	44.6	48.4	47.7
–2.36 mm +75 um flow time (sec)		26.1	26.8	26.2	27.1	24.9	26.3	28.7	23.3
7 d Mortar cubes control – 80% Kurnell:20% Nep	–	–	–	–	–	–	–	–	–
7 d Mortar cubes 100%	–	–	–	–	–	–	–	–	–
7 d Mortar cubes 50%	–	–	–	–	–	–	–	–	–
7 d Mortar cubes 20%	–	–	–	–	–	–	–	–	–
28 d Mortar prism control – 80% Kurnell:20% Nep	55.5	–	–	–	–	–	–	–	–
28 d Mortar prism 100%	–	59	45	51.5	44.5	40.5	60.5	32	19.5
28 d Mortar prism 50%	–	55	46.5	n/a	50.5	43.5	54	39	27
28 d Mortar prism 20%	–	40	39.5	n/a	37.5	35.5	41	35.5	31

continues

EIGHT-SAMPLE PROPERTY SUMMARY including BORAL mortar results *continued*

PROPERTY		Control sample 80% Kur: 20% Nep	1 Sample D69 average	2 Sample G80 average	3 Sample L16 average	4 Sample L24 average	5 Sample N53 average	6 Sample S51 average	7 Sample S68 average	8 Sample T68 average
Density 7 days control – 80% Kurnell:20% Nep		–	–	–	–	–	–	–	–	–
Density 7 days	100%	–	–	–	–	–	–	–	–	–
Density 7 days	50%	–	–	–	–	–	–	–	–	–
Density 7 days	20%	–	–	–	–	–	–	–	–	–
Density 28 days control – 80% Kurnell:20% Nep		2640	–	–	–	–	–	–	–	–
Density 28 days	100%	–	2680	2700	2710	2710	2640	2700	2660	2590
Density 28 days	50%	–	2640	2650	2660	2660	2620	2650	2630	2600
Density 28 days	20%	–	2620	2620	2630	2630	2610	2620	2620	2600
Shrinkage 28 days control – 80% Kurnell:20% Nep		670	–	–	–	–	–	–	–	–
Shrinkage 28 days	100%	–	670	730	n/a	1100	640	450	1320	1760
Shrinkage 28 days	50%	–	–	–	–	–	–	–	–	–
Shrinkage 28 days	20%	–	–	–	–	–	–	–	–	–
W/C ratio control – 80% Kurnell:20% Nep		0.496	–	–	–	–	–	–	–	–
W/C ratio	100%	–	0.511	0.631	0.531	0.600	0.613	0.493	0.762	1.553
W/C ratio	50%	–	0.540	0.598	n/a	0.569	0.602	0.524	0.658	0.760
W/C Ratio	20%	–	0.589	0.627	n/a	0.567	0.638	0.584	0.647	0.622
Flow table control – 80% Kurnell:20% Nep		113	–	–	–	–	–	–	–	–
Flow table	100%	–	112	108	112	107	112	109	108	107
Flow table	50%	–	107	112	n/a	113	111	111	108	113
Flow table	20%	–	109	111	n/a	113	113	110	110	110
Water control – 80% Kurnell:20% Nep		223	–	–	–	–	–	–	–	–
Water	100%	–	230	284	239	270	276	222	343	699
Water	50%	–	243	269	n/a	256	271	236	296	342
Water	20%	–	265	282	n/a	255	287	263	291	280
Workability control – 80% Kurnell:20% Nep		–	–	–	–	–	–	–	–	–
Workability 0 to 10	100%	–	–	–	–	–	–	–	–	–
Workability 0 to 10	50%	–	–	–	–	–	–	–	–	–
Workability 0 to 10	20%	–	–	–	–	–	–	–	–	–

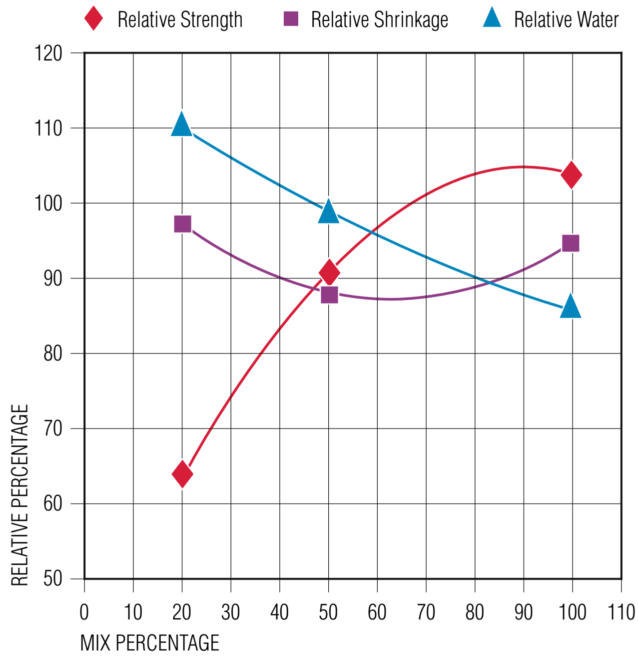
continues

EIGHT-SAMPLE PROPERTY SUMMARY including BORAL mortar results *continued*

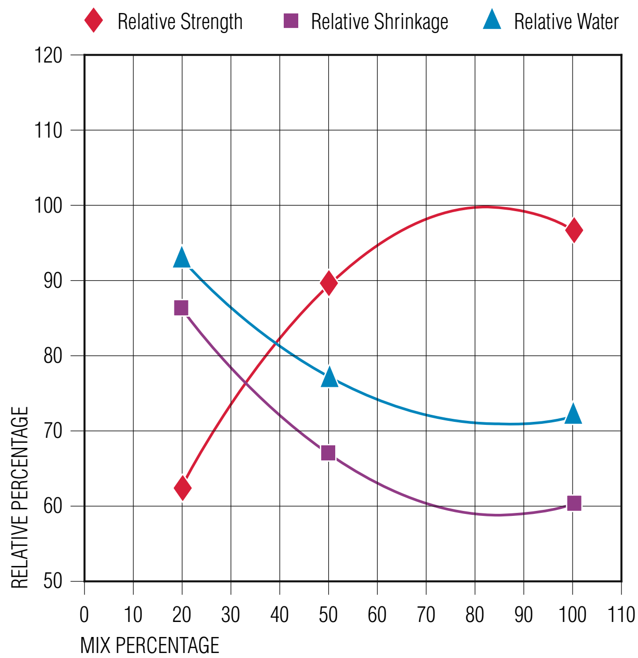
PROPERTY	Control sample 80% Kur: 20% Nep	1 Sample D69 a	2 Sample G80	3 Sample L16	4 Sample L24	5 Sample N53	6 Sample S51	7 Sample S68	8 Sample T68
Ratio bleed:mix water control – 80% Kurnell:20% Nep	–	–	–	–	–	–	–	–	–
Ratio bleed:mix water 100%	–	–	–	–	–	–	–	–	–
Ratio bleed:mix water 50%	–	–	–	–	–	–	–	–	–
Ratio bleed:mix water 20%	–	–	–	–	–	–	–	–	–
Diff in setting time (mins) control – 80% Kurnell:20% Nep	–	–	–	–	–	–	–	–	–
Diff in setting time (mins) 100%	–	–	–	–	–	–	–	–	–
Diff in setting time (mins) 50%	–	–	–	–	–	–	–	–	–
Diff in setting time (mins) 20%	–	–	–	–	–	–	–	–	–
Diff in water from control 100%	nil	7	61	16	47	53	–1	120	476
Diff in water from control 50%	nil	20	46	n/a	33	48	13	73	119
Diff in water from control 20%	nil	42	59	n/a	32	64	40	68	57

Appendix 3

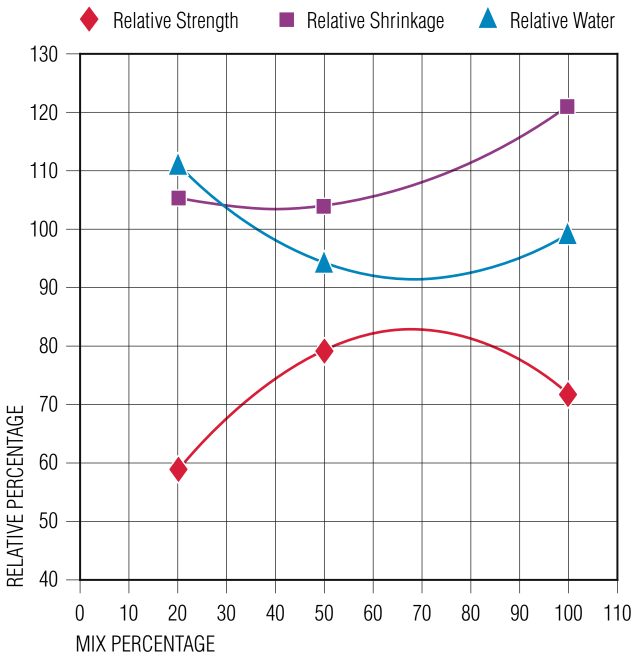
MIX DESIGN CHARTS



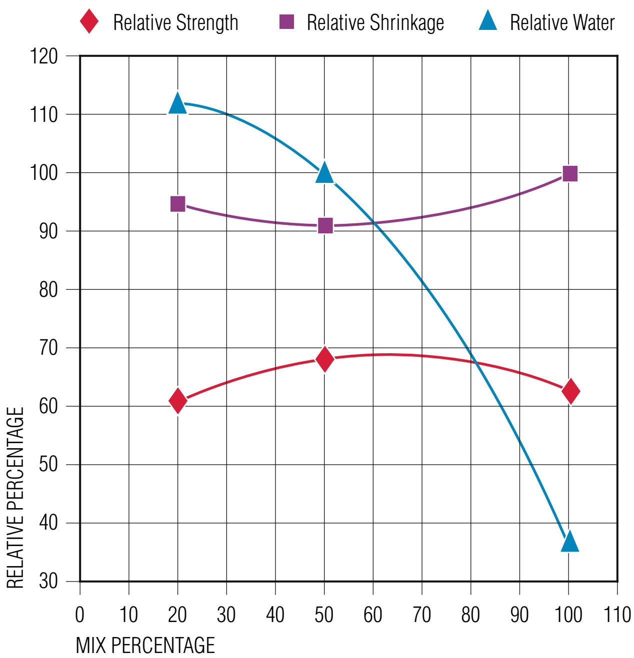
Sample D69



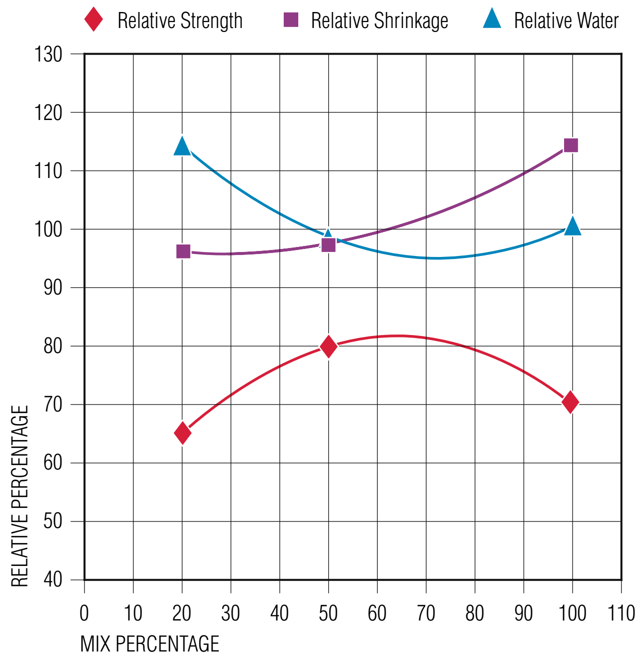
Sample S51



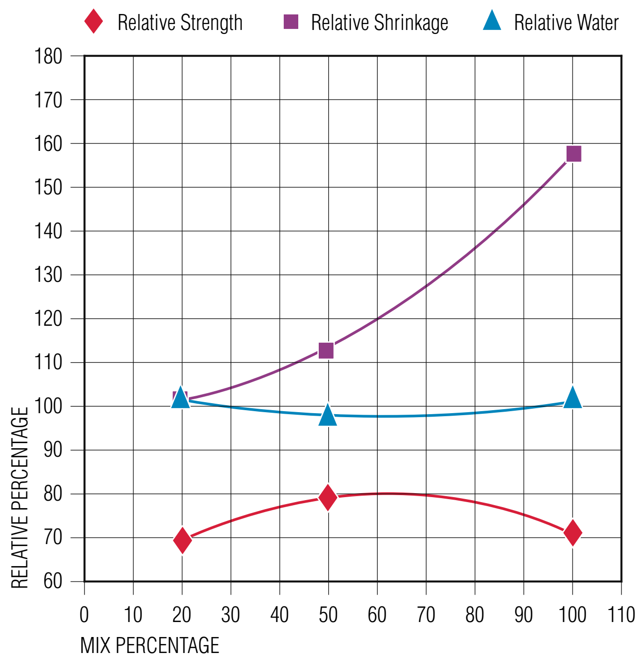
Sample L16



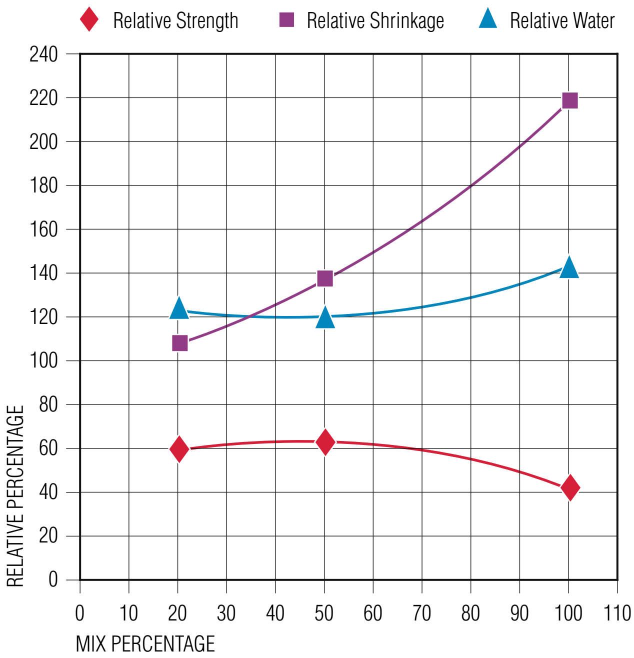
Sample N53



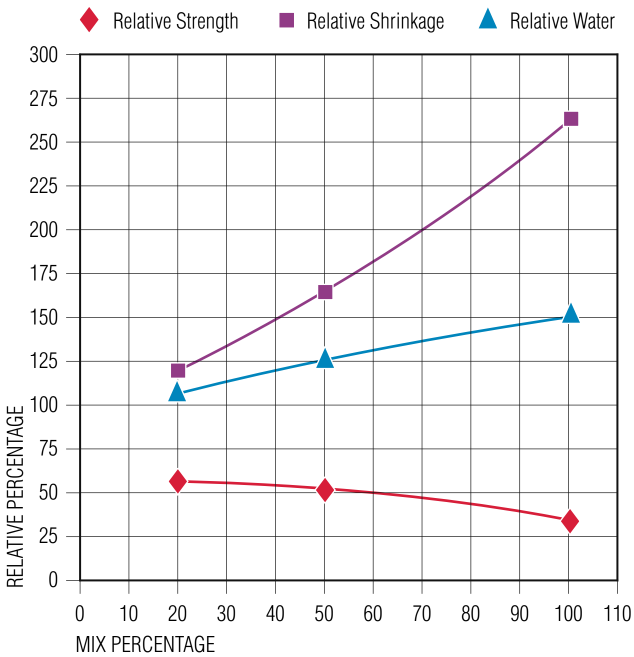
Sample G80



Sample L24



Sample S68



Sample T68