TR 11
Properties of New Zealand Concrete Aggregates

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Cement & Concrete Association of New Zealand

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Introduction

This technical report presents the important concrete-making properties of commonly used aggregate of New Zealand. Traditionally, engineers have considered that concrete aggregates are primarily used to provide bulk and economy to concrete. More recently, it has been realized that aggregates play an important role in enhancing concrete strength and stiffness. This information should hopefully enhance existing knowledge and allow engineers to use the material more effectively rather than relying on generic or outdated performance data.

A national survey was undertaken throughout New Zealand between October 2001 and September 2003. Aggregates were supplied from 26 concrete readymix plants or associated quarries from Kaitaia to Invercargill. Whilst this survey does not study all aggregate types it is sufficiently broad to establish general trends. Further details may also be added as this becomes available.

J.R. Mackechnie

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Materials and Mixes

Details of aggregates used in this project are shown in Table 1. Selection of material was primarily based on covering major urban areas although some smaller areas were included because of the presence of unusual aggregates (e.g. Waiau, Manapouri).

Table 1: Location of Aggregates Used for Testing

Plant No.	Location	Supplier(s)	Coarse Aggregate Geological Type	Fine Aggregate Types
1	Kaitaia	Pukepoto	Andesite/gabbro	Natural/crusher
2	Whangarei	Firth	Greywacke	Natural/crusher
3	Hunua	Firth	Greywacke	Natural/crusher
4	Bombay	Holcim	Basalt	Natural/crusher
5	Pukekawa	Firth	Basalt	Natural/crusher
6	Hamilton	Firth	Greywacke	River/crusher
7	Tauranga	Allied	Andesite	Natural/crusher
8	Hastings	Allied	Greywacke	River sand
9	New Plymouth	Allied	Andesite	Crusher sand
10	Taranaki	Firth	Andesite	Crusher sand
11	Palmerston North	Higgins	Greywacke	River sand
12	Masterton	Oldfields	Greywacke	River sand
13	Wellington	Winstone	Greywacke	Natural/crusher
14	Nelson	Allied	Mixed gravel	River sand
15	Blenheim	Firth	Greywacke	River sand
16	Westport	Local	Granite/greywacke	River sand
17	Kaikoura	Works	Greywacke	River sand
18	Waiau	Amuri	Limestone	Crusher sand
19	Waimakariri	ChCh	Greywacke	Natural/crusher
20	Yaldhurst	Winstone	Greywacke	Natural/crusher
21	Timaru	Allied	Greywacke	River sand
22	Oamaru	Firth	Greywacke	Pit sand
23	Queenstown	Firth	Schist/greywacke	River sand
24	Dunedin	Allied	Phonolite	Pit sand/crusher
25	Manapouri	Meridian	Gneiss/diorite	Crusher sand
26	Invercargill	Allied	Mixed gravel	River sand

Course aggregates were loosely grouped based on their geological type and particle shape. Greywacke aggregates were most common and represented half of all the material tested, with eight types of rounded gravels and four crushed. Mixed gravels were nominally termed greywacke by suppliers but consisted of substantial proportions of other geological types.

In order to be able to compare different concretes, mix designs were standardised as far as possible. The following general limitations were applied to concrete mixes:

- water/cement ratios of 0.7, 0.6 and 0.5 were used for each aggregate type
- workability was set at a slump of 80 mm (range of 50-100 mm)
- stone content kept between 1020-1100 kg/m^3
- air-entrainment of 5-6% used for w/c ratios of 0.7 and 0.6 (North Island only)
- water-reducing admixture used in all concrete mixes
- water demands kept within readymix plants recommendations
- GP cement used (Holcim – South Island, Golden Bay – North Island)

Details of concrete mix designs are shown in Table 2. Concrete was cast in a high shear laboratory pan mixer for five minutes after which samples were compacted on a standard vibrating table, representing ideal conditions.

Table 2: Concrete Mix Proportions (per cubic metre)

North Island Aggregate	Water Demand (L/m^3)	Stone Content (kg/m^3)	South Island Aggregate	Water Demand (L/m^3)	Stone Content (kg/m^3)
Kaitaia	175	1020	Nelson	160	1100
Whangarei	170	1100	Blenheim	155	1100
Hunua	175	1050	Westport	170	1050
Bombay	170	1100	Kaikoura	150	1100
Pukekawa	175	1050	Waiau	175	1100
Hamilton	170	1100	Christchurch	165	1100
Tauranga	175	1020	Timaru	145	1100
Hastings	155	1100	Oamaru	155	1100
New Plymouth	175	1050	Queenstown	155	1100
Palmerston North	160	1100	Dunedin	165	1050
Masterton	160	1100	Manapouri	200	1100
Wellington	170	1100	Invercargill	150	1100

Testing Procedure and Test Results

Aggregates were tested for standard properties such as grading, relative density, absorption, crushing resistance and clay index in accordance with NZS 3111, 3121 and 4407[1,2,3]. Intrinsic shrinkage of coarse aggregates was also measured by casting small prisms of stone particles bound in a low viscosity epoxy and measuring dimension change between the dry and saturated condition. This test method was developed to characterise the shrinking nature of most New Zealand greywacke aggregates.

Concrete was tested for standard properties such as hardened density, compressive strength, tensile splitting strength, elastic modulus and coefficient of thermal expansion in accordance with NZS 3112[4]. Testing was done at 28 days, using 200 x 100 mm cylinders that had been cured in a fog room at 21^{o}C. Drying shrinkage was done in accordance with AS1012.13 where concrete prisms are exposed to a drying environment (23^{o}C and 50% R.H.) from an age of seven days[5].

Effective porosity of concrete was measured by measuring the mass change when concrete is cycled from oven-dry to fully saturated in water. This property is equivalent to volume of permeable voids (VPV) used in Australia[6]. Measuring effective porosity gives a measure of the packing efficiency of the materials.

Plant 1: Kaitaia

Aggregates were supplied by Pukepoto Quarry in July 2002 and concrete was cast in August 2002.

Table 1.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Mangawhai/Crush. PAP5	Crushed 13 mm and 19 mm
Geological Type:	Silica/Basalt gabbro	Basalt gabbro
Colour:	Beige/Dark brown	Dark brown
Particle Shape:	Rounded/angular	Angular
Fineness Modulus:	1.17/3.85	-
Fines Content (%):	1.2/3.9	-
Relative Density:	2.68/2.62	2.62
10% FACT (kN):	-	260
Absorption (%):	-	3.40
Clay Index:	-	-
Intrinsic Shrink ($\mu\varepsilon$):	-	385

Fine aggregates were a blend of dredged Mangawhai and crusher sand with an overall fineness modulus of 2.50. The coarse aggregate was poorly shaped volcanic rock with high absorption values. The aggregates need to be kept wet before batching to prevent rapid stiffening of fresh concrete.

Table 1.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2345	2355	2342	2336
Comp. strength (MPa):	38.5	34.2	31.8	23.8
Split. strength (MPa):	3.3	3.0	3.2	2.8
Elastic modulus (GPa):	28.5	25.6	25.2	20.5
C.T.E. ($\mu\varepsilon$/K):	7.8	8.0	7.5	7.8
Shrinkage-56d($\mu\varepsilon$):	976	936	1000	914
Shrinkage-180d ($\mu\varepsilon$):	1111	1047	1111	983
Effective porosity (%):	17.1	18.0	16.9	18.1

Plant 1 continued

Figure 1: Concrete containing Kaitaia aggregates

Concrete had reasonable mechanical properties but slightly high drying shrinkage results. Compressive strengths were lower than expected and this may be ascribed to the high absorption values of the stone. The poorly shaped coarse aggregates were responsible for poor packing efficiency that produced porosity values between 17 and 18%.

Plant 2: Whangarei

Aggregates were supplied by Firth Industries in February 2003 and concrete cast during the same month.

Table 2.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Beach/Crusher	Crushed 13mm and 19 mm
Geological Type:	Silica/Greywacke	Greywacke
Colour:	Beige/Light grey	Grey
Particle Shape:	Rounded/Angular	Angular – chunky
Fineness Modulus:	1.31/3.68	-
Fines Content (%):	4.3/2.6	-
Relative Density:	2.64/2.60	2.60
10% FACT (kN):	-	425
Absorption (%):	-	0.49
Clay Index:	-	1.25
Intrinsic Shrink ($\mu\varepsilon$):	-	255

Fine aggregates were a blend of beach and crusher sands with an overall fineness modulus of 2.50. Coarse aggregate was a high strength, well shaped stone with low absorption characteristics.

Table 2.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2425	2390	2395	2400
Comp. strength (MPa):	43.5	32.5	34.1	24.5
Split. strength (MPa):	4.2	3.7	3.5	3.1
Elastic modulus (GPa):	40.2	35.9	33.4	31.0
C.T.E. ($\mu\varepsilon$/K):	9.2	9.0	9.6	9.4
Shrinkage-56d($\mu\varepsilon$):	618	664	718	515
Shrinkage-180d ($\mu\varepsilon$):	750	824	898	620
Effective porosity (%):	11.6	11.5	11.8	11.7

Plant 2 continued

Figure 2: Concrete containing Whangarei aggregates

The crushed greywacke aggregates produced concrete with high elastic stiffness and low shrinkage characteristics despite having moderate strengths. Effective porosity values were relatively low indicating good packing efficiency of the material.

Plant 3: Hunua

Aggregates were supplied by Winstone Aggregates in November 2002 and concrete cast during that month.

Table 3.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Kaipara/Crusher PAP 7	Crushed 13mm and 19 mm
Geological Type:	Silica/Greywacke	Greywacke
Colour:	Beige/Dark brown	Dark brown
Particle Shape:	Rounded/Angular	Angular
Fineness Modulus:	1.26/3.31	-
Fines Content (%):	1.9/5.9	-
Relative Density:	2.64/2.67	2.70
10% FACT (kN):	-	360
Absorption (%):	-	0.72
Clay Index:	-	1.05
Intrinsic Shrink (με):	-	428

Fine aggregates were a blend of sea-dredged and crusher sands with an overall fineness modulus of 2.30. The crushed greywacke was a reasonable quality material with good shape and strength characteristics.

Table 3.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2389	2358	2376	2341
Comp. strength (MPa):	44.8	34.1	35.3	27.3
Split. strength (MPa):	3.7	3.4	3.5	3.3
Elastic modulus (GPa):	36.5	34.5	35.2	30.0
C.T.E. (με/K):	9.0	8.6	8.6	9.2
Shrinkage-56d(με):	850	718	826	833
Shrinkage-180d (με):	1107	947	1079	1078
Effective porosity (%):	13.0	12.5	13.2	12.8

Plant 3 continued

Figure 3: Concrete containing Hunua aggregates

Concrete made with Hunua aggregates had reasonably good hardened properties with elastic modulus values in excess of 30 GPa and drying shrinkage of less than 850 microstrain at 56 days. The effective porosity of concrete was within the normal range around 13%.

Plant 4: Bombay

Aggregates were supplied by Holcim Aggregates in October 2002 and concrete was cast during the same month.

Table 4.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Kaipara/Crusher PAP7	Crushed 13 mm and 19 mm
Geological Type:	Silica/Basalt	Basalt
Colour:	Beige/Dark grey	Dark grey
Particle Shape:	Rounded/angular	Angular – chunky
Fineness Modulus:	1.15/3.64	-
Fines Content (%):	9.0/8.7	-
Relative Density:	2.65/2.70	2.75
10% FACT (kN):	-	288
Absorption (%):	-	1.30
Clay Index:	-	-
Intrinsic Shrink (με):	-	90

Fine aggregates were a blend of sea-dredged and crusher sands with an overall fineness modulus of 2.40 and a fines content of 8.9%. Coarse aggregate was a well-shaped material with reasonable strength and good stability.

Table 4.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2455	2454	2443	2441
Comp. strength (MPa):	51.0	35.0	42.5	29.7
Split. strength (MPa):	4.1	3.5	3.4	3.3
Elastic modulus (GPa):	35.6	34.5	33.3	31.8
C.T.E. (με/K):	8.5	9.8	9.7	8.8
Shrinkage-56d(με):	733	778	711	650
Shrinkage-180d (με):	890	943	876	814
Effective porosity (%):	13.1	13.0	14.4	14.7

Plant 4 continued

Figure 4: Concrete containing Bombay aggregates

Good compressive and tensile splitting strengths were obtained across the range of water/cement ratios. Concrete also had high elastic stiffness and relatively low drying shrinkage characteristics. Effective porosities were slightly higher than normal however indicating less than optimal packing efficiency.

Plant 5: Pukekawa

Aggregates were supplied by Winstone Aggregates in November 2002 and concrete cast in December 2002.

Table 5.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Helensville/Crusher PAP7	Crushed 13mm and 19 mm
Geological Type:	Silica/Basalt	Basalt
Colour:	Beige/Dark grey	Dark grey
Particle Shape:	Rounded/Angular	Angular
Fineness Modulus:	1.16/3.02	-
Fines Content (%):	4.8/16.9	-
Relative Density:	2.65/2.80	2.85
10% FACT (kN):	-	275
Absorption (%):	-	1.31
Clay Index:	-	-
Intrinsic Shrink ($\mu\varepsilon$):	-	120

Fine aggregate was a blend of sea-dredged and crusher sand with an overall fineness modulus of 2.10. Coarse aggregate was an angular shaped material with reasonable strength and absorption values.

Table 5.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2545	2555	2520	2560
Comp. strength (MPa):	54.5	44.0	40.5	30.5
Split. strength (MPa):	4.4	4.0	3.8	3.6
Elastic modulus (GPa):	37.7	36.5	33.8	32.6
C.T.E. ($\mu\varepsilon$/K):	9.1	9.6	9.6	9.2
Shrinkage-56d($\mu\varepsilon$):	707	714	676	604
Shrinkage-180d ($\mu\varepsilon$):	840	854	807	743
Effective porosity (%):	14.1	14.6	13.8	14.6

Plant 5 continued

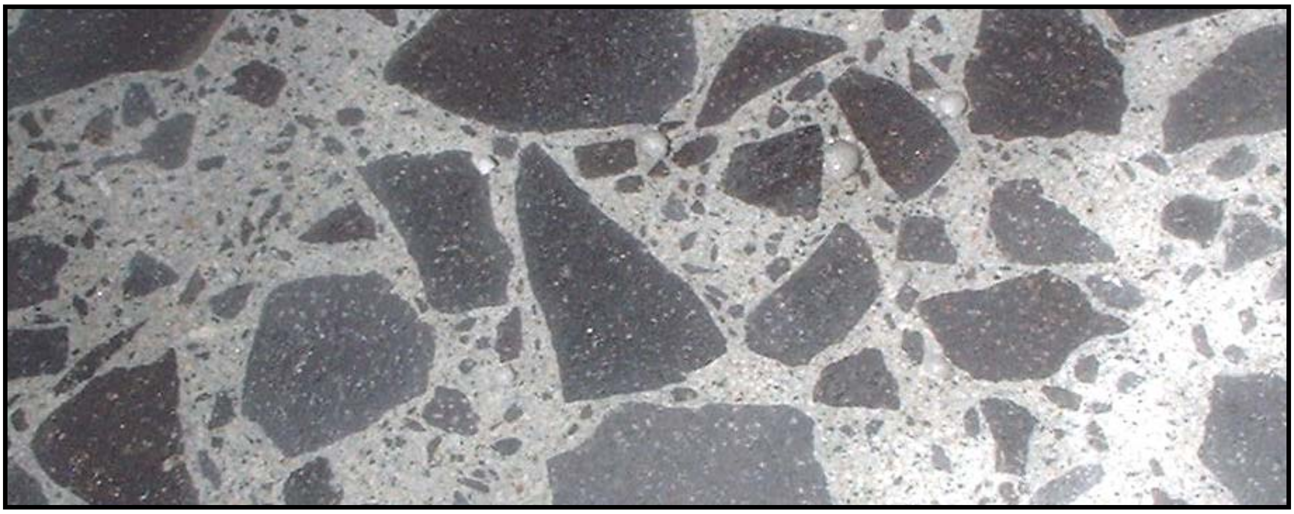

Figure 5: Concrete containing Pukekawa aggregates

Concrete made with Pukekawa basalt had excellent strength characteristics and high elastic stiffness (ranging from 32 –38 MPa). Drying shrinkage values were consistently low with all 56 day measurements being less than 750 microstrain. Effective porosity measurements were within the normal range.

Plant 6: Hamilton

Aggregates were supplied by Firth Industries (Te Rapa) in August 2002 and concrete cast in September 2002.

Table 6.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	River/Crusher	Crushed 13 mm and 19 mm
Geological Type:	Greywacke/Greywacke	Greywacke
Colour:	Light brown/Grey	Grey
Particle Shape:	Rounded/Angular	Angular
Fineness Modulus:	2.25/3.19	-
Fines Content (%):	3.9/8.7	-
Relative Density:	2.68/2.68	2.71
10% FACT (kN):	-	365
Absorption (%):	-	0.68
Clay Index:	-	2.13
Intrinsic Shrink ($\mu\varepsilon$):	-	375

Fine aggregate was a blend of river and crusher sand with an overall fineness modulus of 2.70. The coarse aggregate was a hard and reasonable well-shaped material with low absorption values. The clay index value for this material was relatively high at 2.1.

Table 6.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2432	2415	2381	2355
Comp. strength (MPa):	43.4	33.6	33.2	26.5
Split. strength (MPa):	4.2	3.9	3.4	3.1
Elastic modulus (GPa):	34.9	32.9	33.7	27.9
C.T.E. ($\mu\varepsilon$/K):	10.1	10.0	9.5	9.1
Shrinkage-56d($\mu\varepsilon$):	826	793	840	771
Shrinkage-180d ($\mu\varepsilon$):	961	904	965	850
Effective porosity (%):	12.1	13.7	12.4	15.3

Plant 6 continued

Figure 6: Concrete containing Hamilton aggregates

Concrete made with Hamilton greywacke aggregate had moderate strength and slightly high elastic stiffness and drying shrinkage. Effective porosity values were generally within the normal range with the exception of concrete made with water/cement ratio of 0.7.

Plant 7: Tauranga

Aggregates were supplied by Allied Concrete in October 2002 and concrete cast in the same month.

Table 7.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Dune/Crusher	Crushed 13 mm and 19 mm
Geological Type:	Silica/Andesite	Andesite
Colour:	Light brown/Grey	Brown
Particle Shape:	Rounded/Angular	Angular
Fineness Modulus:	2.02/3.44	-
Fines Content (%):	8.4/3.8	-
Relative Density:	2.65/2.58	2.58
10% FACT (kN):	-	275
Absorption (%):	-	2.1
Clay Index:	-	-
Intrinsic Shrink (με):	-	465

Fine aggregate was a blend of dune and crusher sand with an overall fineness modulus of 2.70. Coarse aggregate was crushed andesite with an angular shape and moderate strength and absorption characteristics.

Table 7.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2310	2285	2270	2265
Comp. strength (MPa):	48.5	36.7	32.5	22.4
Split. strength (MPa):	4.1	3.8	3.4	2.9
Elastic modulus (GPa):	29.6	27.8	28.5	25.4
C.T.E. (με/K):	8.4	7.7	8.6	8.3
Shrinkage-56d(με):	990	1000	1061	947
Shrinkage-180d (με):	1140	1147	1211	1071
Effective porosity (%):	13.6	13.8	13.7	14.3

Plant 7 continued

Figure 7: Concrete containing Tauranga aggregates

Concrete had moderate strength and elastic modulus and porosity values within the normal range. Drying shrinkage values were slightly high but coefficient of thermal expansion values were low as is typically found with concrete containing andesite aggregates.

Plant 8: Hastings

Aggregates were supplied by Allied Concrete in October 2002 and concrete cast during November 2002.

Table 8.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Natural alluvial	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Brown	Brown-grey
Particle Shape:	Subrounded	Rounded-elongated
Fineness Modulus:	2.76	-
Fines Content (%):	3.6	-
Relative Density:	2.62	2.62
10% FACT (kN):	-	312
Absorption (%):	-	1.00
Clay Index:	-	1.43
Intrinsic Shrink (με):	-	533

Fine aggregate was natural alluvial sand with a good grading but low fines content. Coarse aggregate was a smooth stone with reasonable shape and hardness.

Table 8.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2363	2322	2315	2311
Comp. strength (MPa):	47.1	32.3	35.4	21.4
Split. strength (MPa):	4.4	3.5	3.2	2.7
Elastic modulus (GPa):	33.8	30.5	32.1	29.0
C.T.E. (με/K):	8.4	8.6	8.6	8.8
Shrinkage-56d(με):	997	886	933	921
Shrinkage-180d (με):	1226	1069	1125	1114
Effective porosity (%):	12.3	12.8	11.8	12.1

Plant 8 continued

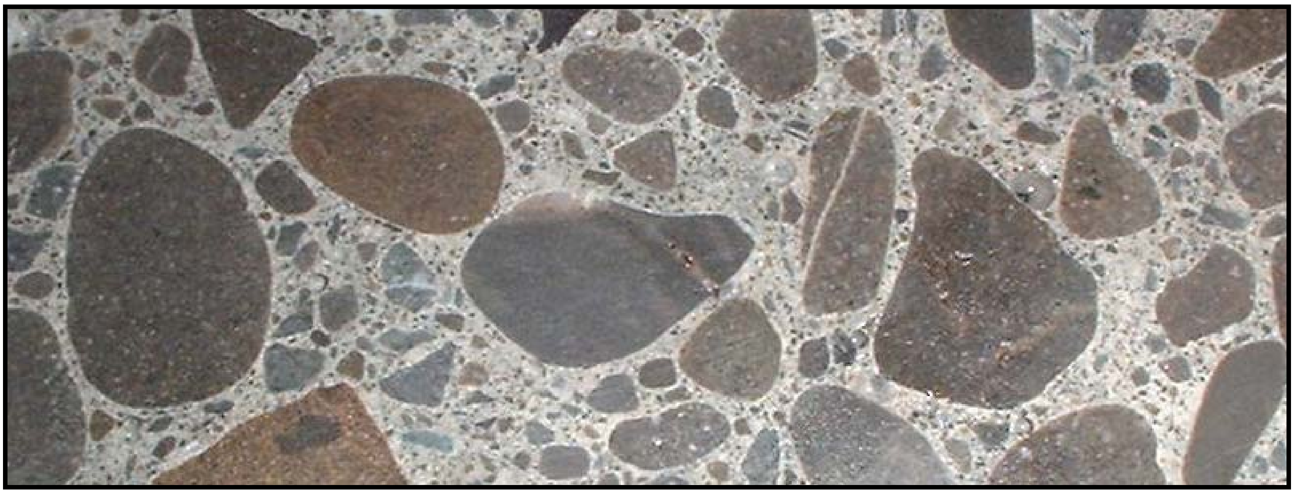

Figure 8: Concrete containing Hastings aggregate

Concrete had good strength and stiffness characteristics while drying shrinkage was slightly high. Thermal expansion was lower than normal for concrete containing greywacke aggregate but effective porosity values were within the normally expected range.

Plant 9: New Plymouth

Aggregates were supplied by Allied Concrete in January 2003 and concrete cast in February 2003.

Table 9.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Crusher	Crushed 9 mm and 19 mm
Geological Type:	Andesite	Andesite
Colour:	Dark grey	Dark grey
Particle Shape:	Angular	Angular-chunky
Fineness Modulus:	2.37	-
Fines Content (%):	10.9	-
Relative Density:	2.60	2.60
10% FACT (kN):	-	125
Absorption (%):	-	2.39
Clay Index:	-	-
Intrinsic Shrink ($\mu\varepsilon$):	-	220

Fine aggregate was a well-graded crusher sand with high fines content. Coarse aggregate was a crushed material of relatively low hardness and high absorption characteristics.

Table 9.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2345	2365	2325	2317
Comp. strength (MPa):	55.8	38.5	30.0	24.7
Split. strength (MPa):	4.0	3.4	3.5	2.7
Elastic modulus (GPa):	21.6	22.0	21.5	16.8
C.T.E. ($\mu\varepsilon$/K):	6.7	7.0	7.0	6.6
Shrinkage-56d($\mu\varepsilon$):	897	840	704	705
Shrinkage-180d ($\mu\varepsilon$):	1080	1013	846	840
Effective porosity (%):	17.2	16.8	17.6	17.8

Plant 9 continued

Figure 9: Concrete containing New Plymouth aggregates

Whilst compressive and tensile strengths of concrete were within the normal range, elastic modulus values were significantly below predicted NZS 3101 values. The low elastic stiffness of the concrete may be ascribed to the relatively low crushing strength of the andesite aggregate. Drying shrinkage values were within the normal range but effective porosity values were relatively high.

Plant 10: Taranaki

Aggregates were supplied by Firth Industries in January 2003 and concrete was cast in February 2003.

Table 10.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Crusher	Crushed 9 mm and 19 mm
Geological Type:	Andesite	Andesite
Colour:	Dark grey	Dark grey
Particle Shape:	Angular	Angular
Fineness Modulus:	2.50	-
Fines Content (%):	9.1	-
Relative Density:	2.60	2.63
10% FACT (kN):	-	127
Absorption (%):	-	2.79
Clay Index:	-	-
Intrinsic Shrink (με):	-	200

Fine aggregate was a well-graded crusher sand with high fines content. Coarse aggregate was a crushed material of relatively low hardness and high absorption characteristics.

Table 10.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2387	2393	2365	2355
Comp. strength (MPa):	53.5	42.0	29.5	30.8
Split. strength (MPa):	3.9	3.6	3.3	2.8
Elastic modulus (GPa):	23.4	22.9	22.7	21.5
C.T.E. (με/K):	7.0	7.3	7.2	6.5
Shrinkage-56d(με):	818	761	719	679
Shrinkage-180d (με):	1021	955	902	855
Effective porosity (%):	16.5	16.6	17.1	16.9

Plant 10 continued

Figure 10: Concrete containing Taranaki aggregates

As with concrete from Allied New Plymouth, compressive and tensile strengths of concrete were within the normal range but elastic modulus values were significantly below predicted NZS 3101 values. The low elastic stiffness of the concrete may be ascribed to the relatively low crushing strength of the andesite aggregate. Drying shrinkage values were within the normal range but effective porosity values were relatively high.

Plant 11: Palmerston North

Aggregates were supplied by Higgins Readymix in August 2002 and concrete cast in September 2002.

Table 11.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Rangitikei River	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Grey-brown	Grey-brown
Particle Shape:	Rounded-chunky	Elongated-rounded
Fineness Modulus:	2.80	-
Fines Content (%):	5.7	-
Relative Density:	2.65	2.62
10% FACT (kN):	-	305
Absorption (%):	-	1.35
Clay Index:	-	1.33
Intrinsic Shrink ($\mu\varepsilon$):	-	623

Fine aggregate was a well-graded natural sand from the Rangitikei River. Coarse aggregate was a composite greywacke gravel, containing a range of particle shapes and colours.

Table 11.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m^3):	2345	2355	2305	2320
Comp. strength (MPa):	38.8	30.9	27.8	23.8
Split. strength (MPa):	3.5	3.2	3.3	2.6
Elastic modulus (GPa):	27.8	26.1	22.5	21.2
C.T.E. ($\mu\varepsilon$/K):	10.5	11.0	10.0	10.2
Shrinkage-56d($\mu\varepsilon$):	1236	1336	1204	1183
Shrinkage-180d ($\mu\varepsilon$):	1371	1447	1326	1311
Effective porosity (%):	13.1	12.4	14.0	12.9

Plant 11 continued

Figure 11: Concrete containing Palmerston-North aggregates

Concrete had slightly low compressive and tensile strength that resulted in marginally lower than normal elastic modulus values. Coefficient of thermal expansion and effective porosity values were within the normal range. Drying shrinkage values were extremely high despite the relatively low water demand of the concrete (160 L/m^3) and may be ascribed to the high intrinsic shrinkage of the aggregate.

Plant 12: Masterton

Aggregates were supplied by Oldfields Readymix in August 2002 and concrete cast in September 2002.

Table 12.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Waingawa River	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Dark brown	Light grey
Particle Shape:	Rounded-angular	Elongated
Fineness Modulus:	2.90	-
Fines Content (%):	6.5	-
Relative Density:	2.60	2.55
10% FACT (kN):	-	390
Absorption (%):	-	1.44
Clay Index:	-	1.23
Intrinsic Shrink (με):	-	728

Fine aggregate was a reasonably graded natural sand from the Waingawa River. Coarse aggregate was a relatively light, greywacke gravel brought down from the Tararua Ranges.

Table 12.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.6A**	**0.7A**
Density (kg/m³):	2384	2387	2325	2358
Comp. strength (MPa):	50.4	30.3	27.4	23.8
Split. strength (MPa):	4.7	3.5	3.5	2.9
Elastic modulus (GPa):	27.0	25.5	25.2	24.6
C.T.E. (με/K):	10.7	11.2	11.2	10.3
Shrinkage-56d(με):	1097	1054	1305	1204
Shrinkage-180d (με):	1314	1250	1450	1383
Effective porosity (%):	13.4	12.4	13.7	13.2

Plant 12 continued

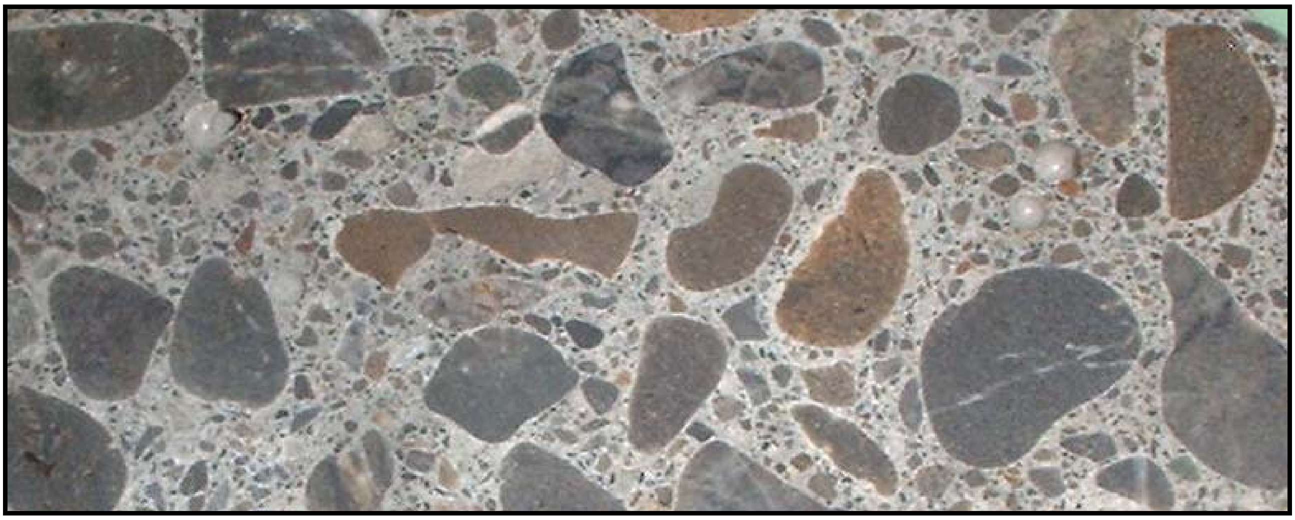

Figure 12: Concrete containing Masterton aggregates

Hardened properties of concrete were generally fairly consistent and within normal limits. Drying shrinkage of concrete was however fairly high (due to high intrinsic shrinkage of local aggregates) while coefficient of thermal expansion values were also higher than normal.

Plant 13: Wellington

Aggregates were supplied by Winstone Aggregates in September 2002 and concrete cast in October 2002

Table 13.1: Aggregate Properties

Type:	Sand	Stone
Source:	Natural/Crusher	Crushed 13 mm and 19 mm
Geological Type:	Greywacke/Greywacke	Greywacke
Colour:	Grey/Grey	Grey-brown
Particle Shape:	Rounded/Angular	Angular
Fineness Modulus:	1.35/3.51	-
Fines Content (%):	19.7/3.4	-
Relative Density:	2.62/2.62	2.60
10% FACT (kN):	-	410
Absorption (%):	-	0.88
Clay Index:	-	1.15
Intrinsic Shrink ($\mu\varepsilon$):	-	736

Fine aggregate was a blend of natural and crusher sand with an overall fineness modulus of 2.43 and a high fines content. Coarse aggregate was a crushed material with excellent crushing resistance.

Table 13.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	0.5	0.6	0.6A	0.7A
Density (kg/m^3):	2327	2352	2384	2374
Comp. strength (MPa):	41.5	33.7	36.9	29.9
Split. strength (MPa):	3.9	3.5	3.8	3.3
Elastic modulus (GPa):	33.6	30.5	32.4	29.8
C.T.E. ($\mu\varepsilon$/K):	9.2	9.5	9.0	9.1
Shrinkage-56d($\mu\varepsilon$):	1264	1240	1233	1119
Shrinkage-180d ($\mu\varepsilon$):	1481	1468	1450	1357
Effective porosity (%):	12.2	12.6	11.6	12.7

Plant 13 continued

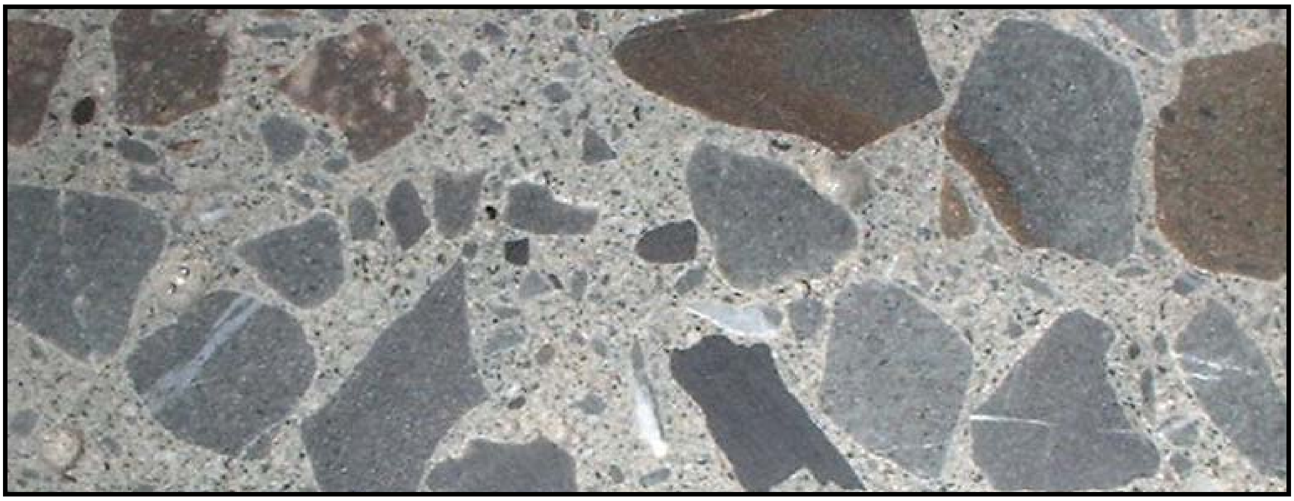

Figure 13: Concrete containing Wellington aggregate

Concrete containing Wellington greywacke produced normal hardened properties with the exception of drying shrinkage results that were high. This greywacke has high levels of intrinsic shrinkage, particularly when contaminated with more marginal browner material (argillite rock).

Plant 14: Nelson

Aggregates were supplied by Allied Concrete in April 2002 and concrete tested during that month.

Table 14.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Pit sand	13 mm and 19 mm gravel
Geological Type:	Mixed greywacke	Greywacke-siltstone
Colour:	Brown	Mixed (green, red, grey)
Particle Shape:	Angular-rounded	Elongated-rounded
Fineness Modulus:	2.75	-
Fines Content (%):	7.2	-
Relative Density:	2.60	2.60
10% FACT (kN):	-	220
Absorption (%):	-	1.72
Clay Index:	-	1.33
Intrinsic Shrink (με):	-	632

Fine aggregate was alluvial pit sand with a slightly coarse fraction but reasonable fines content. Coarse aggregate was composite gravel containing a range of particles from relatively soft mudstone and siltstone to harder greywacke.

Table 14.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2475	2425	2404
Comp. strength (MPa):	37.5	32.0	23.0
Split. strength (MPa):	4.1	3.3	3.0
Elastic modulus (GPa):	26.9	25.5	23.1
C.T.E. (με/K):	10.6	10.1	9.6
Shrinkage-56d (με):	1168	1097	1083
Shrinkage-180d (με):	1404	1286	1247
Effective porosity (%):	11.5	12.5	13.3

Plant 14 continued

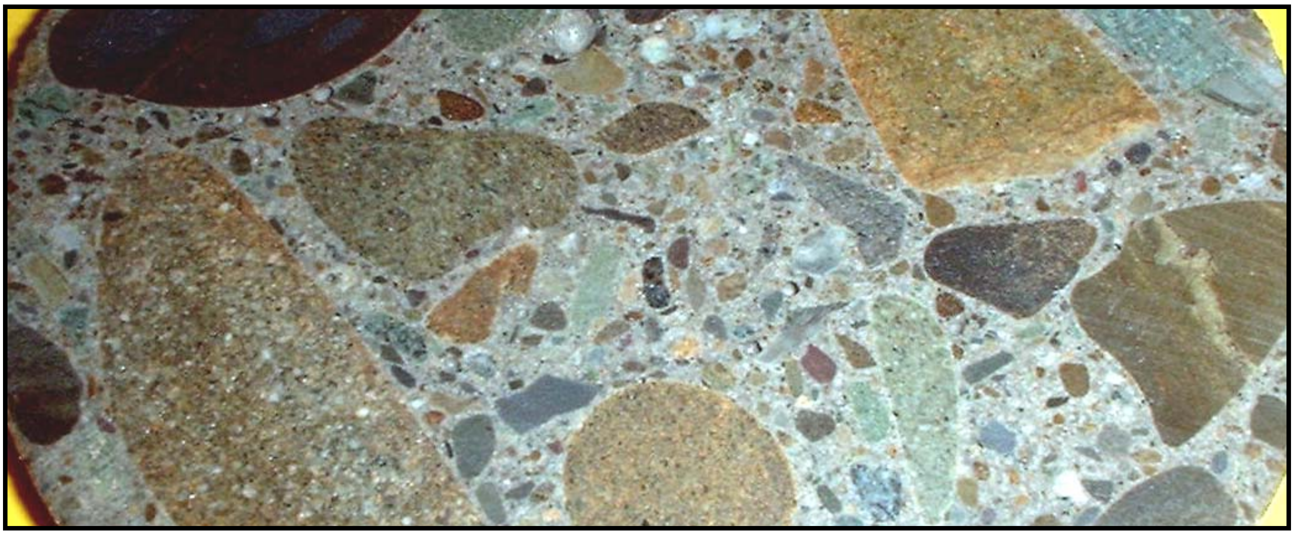

Figure 14: Concrete containing Nelson aggregate

Concrete exhibited normal strength properties but lower than expected elastic modulus values. Drying shrinkage results were high due to the contributory effect of intrinsic shrinkage of aggregates. Effective porosity and coefficient of thermal expansion were within the normal range.

Plant 15: Blenheim

Aggregates were supplied by Firth Industries in December 2002 and concrete cast in January 2003.

Table 15.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Wairau River	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Grey	Grey
Particle Shape:	Rounded	Elongated-rounded
Fineness Modulus:	2.35	-
Fines Content (%):	9.4	-
Relative Density:	2.63	2.62
10% FACT (kN):	-	404
Absorption (%):	-	0.90
Clay Index:	-	0.98
Intrinsic Shrink (με):	-	670

Fine aggregate was a reasonably well-graded river sand from the Wairau River. Coarse aggregate was a hard greywacke gravel with moderate absorption but relatively high intrinsic shrinkage.

Table 15.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m³):	2355	2339	2330
Comp. strength (MPa):	38.6	30.5	23.0
Split. strength (MPa):	3.5	3.3	2.5
Elastic modulus (GPa):	29.4	28.5	24.2
C.T.E. (με/K):	9.4	8.8	9.0
Shrinkage-56d (με):	1104	1128	1214
Shrinkage-180d (με):	1275	1282	1355
Effective porosity (%):	13.6	13.4	13.5

Plant 15 continued

Figure 15: Concrete containing Blenheim aggregates

Concrete had moderate strength and elastic stiffness, slightly low coefficient of thermal expansion values and high drying shrinkage characteristics. Effective porosity values were slightly high indicating that packing efficiency was not optimum.

Plant 16: Westport

Aggregates were obtained from the Buller River near Westport in January 2002 and concrete cast in March 2002.

Table 16.1: Aggregate properties

Type:	**Sand**	**Stone**
Source:	Buller River	19 mm gravel
Geological Type:	Granite-greywacke	Granite-greywacke
Colour:	Brown-grey	Speckled-grey
Particle Shape:	Rounded	Rounded
Fineness Modulus:	2.72	-
Fines Content (%):	4.8	-
Relative Density:	2.70	2.70
10% FACT (kN):	-	165
Absorption (%):	-	0.88
Clay Index:	-	0.53
Intrinsic Shrink (με):	-	90

Fine aggregate was a coarse river sand with a reasonable grading curve. Coarse aggregate was a river gravel with low crushing resistance and moderate absorption characteristics.

Table 16.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2372	2367	2343
Comp. strength (MPa):	43.0	31.5	19.0
Split. strength (MPa):	3.5	2.9	2.1
Elastic modulus (GPa):	24.0	22.6	18.1
C.T.E. (με/K):	9.4	9.9	9.8
Shrinkage-56d (με):	586	626	611
Shrinkage-180d (με):	722	776	735
Effective porosity (%):	10.4	11.4	13.5

Plant 16 continued

Figure 16: Concrete containing Westport aggregates

Concrete had moderate strength but low elastic modulus values as would be anticipated from the low crushing strength of the coarse aggregate. Coefficient of thermal expansion and porosity values were within the normal range while drying shrinkage results were relatively low.

Plant 17: Kaikoura

Aggregates were supplied by Works Infrastructure in November 2001 and concrete cast in January 2002.

Table 17.1: Aggregate Properties

Type:	Sand	Stone
Source:	Natural/Crusher	12 mm and 16 mm gravel
Geological Type:	Greywacke/Greywacke	Greywacke
Colour:	Brown/Grey	Grey
Particle Shape:	Rounded/Subangular	Elongated
Fineness Modulus:	2.37/3.35	-
Fines Content (%):	3.8/4.2	-
Relative Density:	2.63/2.63	2.63
10% FACT (kN):	-	295
Absorption (%):	-	1.04
Clay Index:	-	0.98
Intrinsic Shrink (με):	-	788

Fine aggregate was a blend of natural and crusher sand with an overall fineness modulus of 2.90. Coarse aggregate was a poorly shaped gravel with moderate crushing resistance and slightly high absorption.

Table 17.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	0.5	0.6	0.7
Density (kg/m^3):	2434	2412	2401
Comp. strength (MPa):	46.5	27.5	20.5
Split. strength (MPa):	3.7	3.0	2.4
Elastic modulus (GPa):	32.6	29.9	25.5
C.T.E. (με/K):	9.4	9.4	9.5
Shrinkage-56d (με):	1104	993	1043
Shrinkage-180d (με):	1518	1333	1411
Effective porosity (%):	9.9	11.7	11.9

Plant 17 continued

Figure 17: Concrete containing Kaikoura aggregates

Reasonable mechanical properties were achieved by the concrete and surprisingly low porosity values. Drying shrinkage values were high, partly due to the high intrinsic shrinkage of the local aggregate. Thermal expansion of the concrete was moderate.

Plant 18: Waiau

Aggregates were supplied by Amuri Limestone in January 2002 and concrete cast in February 2002.

Table 18.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Crusher	Crushed 16 mm
Geological Type:	Limestone	Limestone
Colour:	Beige	Beige
Particle Shape:	Angular	Angular
Fineness Modulus:	2.40	-
Fines Content (%):	10.2	-
Relative Density:	2.60	2.60
10% FACT (kN):	-	125
Absorption (%):	-	1.21
Clay Index:	-	-
Intrinsic Shrink (με):	-	130

Fine aggregate used was a well-graded crushed limestone material with a high fines content. Coarse aggregate was a crushed stone with low crushing resistance and relatively high absorption.

Table 18.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2388	2379	2404
Comp. strength (MPa):	49.5	37.0	30.0
Split. strength (MPa):	3.9	3.7	3.1
Elastic modulus (GPa):	32.5	31.4	29.8
C.T.E. (με/K):	6.9	6.8	7.4
Shrinkage-56d (με):	433	440	397
Shrinkage-180d (με):	578	568	511
Effective porosity (%):	10.6	12.6	11.7

Plant 18 continued

Figure 18: Concrete containing Waiau aggregates

Concrete had relatively good hardened properties, with exceptionally low drying shrinkage and thermal expansion. The elastic modulus results were somewhat surprising given the relatively low crushing strength of the coarse aggregate.

Plant 19: Waimakariri

Aggregate was supplied by Christchurch Readymix in January 2003 and concrete cast in February 2003.

Table 19.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Natural	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Grey	Grey
Particle Shape:	Rounded	Rounded
Fineness Modulus:	2.73	-
Fines Content (%):	7.8	-
Relative Density:	2.63	2.63
10% FACT (kN):	-	430
Absorption (%):	-	0.78
Clay Index:	-	0.83
Intrinsic Shrink (με):	-	508

Fine aggregates were a slightly gap-graded river sand with reasonable fines content. Coarse aggregate was a river gravel with high crushing resistance and moderate absorption.

Table 19.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2397	2340	2352
Comp. strength (MPa):	40.0	28.5	22.9
Split. strength (MPa):	4.3	4.1	3.4
Elastic modulus (GPa):	32.1	31.4	27.9
C.T.E. (με/K):	9.5	9.9	9.4
Shrinkage-56d (με):	828	679	685
Shrinkage-180d (με):	940	854	804
Effective porosity (%):	12.7	12.4	11.9

Plant 19 continued

Figure 19: Concrete containing Waimakariri aggregates

Concrete had moderate strength and elastic modulus values but had relatively low drying shrinkage results. Thermal expansion and effective porosity were within the normal range for high quality concrete.

Plant 20: Yaldhurst

Aggregates were supplied by Winstone Aggregates in January and concrete cast during the same month.

Table 20.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Natural/Crusher	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Grey	Grey
Particle Shape:	Rounded/Angular	Rounded-semicrushed
Fineness Modulus:	2.60/2.91	-
Fines Content (%):	6.0/7.5	-
Relative Density:	2.63/2.63	2.63
10% FACT (kN):	-	415
Absorption (%):	-	0.79
Clay Index:	-	0.81
Intrinsic Shrink ($\mu\varepsilon$):	-	448

Fine aggregate was a blend of natural and crusher sand with an overall fineness modulus of 2.75. Coarse aggregate was semi-crushed gravel with high crushing resistance and moderate absorption.

Table 20.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2434	2435	2406
Comp. strength (MPa):	49.5	37.5	27.5
Split. strength (MPa):	4.3	4.1	3.4
Elastic modulus (GPa):	32.1	31.4	27.9
C.T.E. ($\mu\varepsilon$/K):	9.5	9.9	9.4
Shrinkage-56d ($\mu\varepsilon$):	729	726	669
Shrinkage-180d ($\mu\varepsilon$):	1083	1104	1004
Effective porosity (%):	11.1	11.3	12.2

Plant 20 continued

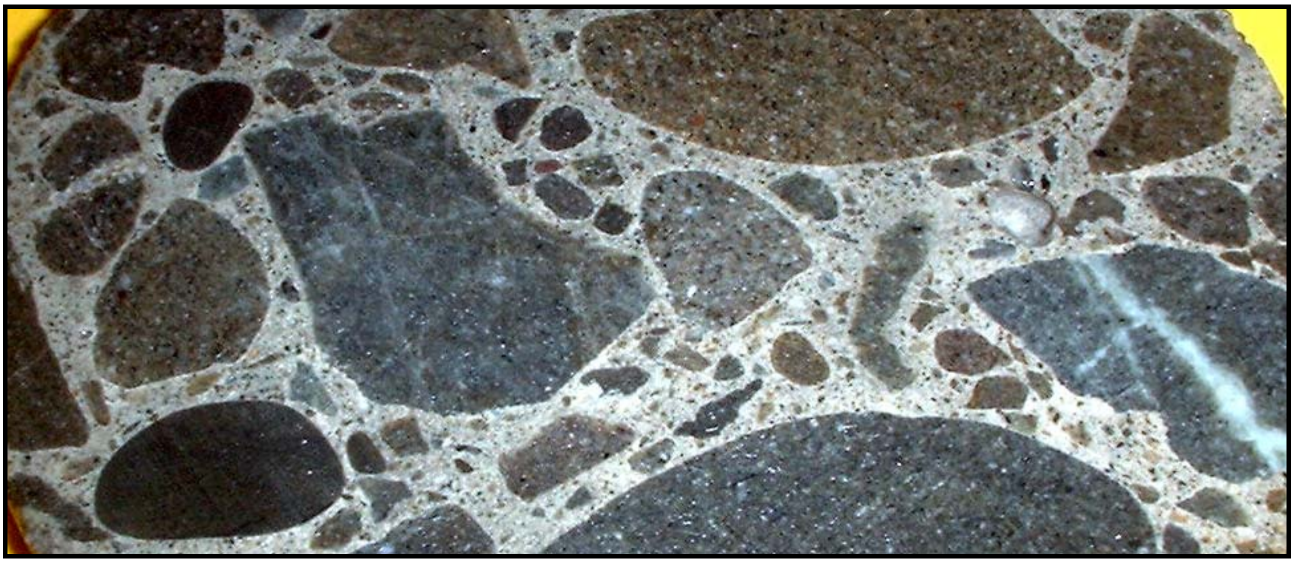

Figure 20: Concrete containing Yaldhurst aggregates

Concrete had good strength and elastic modulus values that was expected from such hard aggregates. Thermal expansion and porosity were relatively low while drying shrinkage was lower than expected for Christchurch concrete (normally above 800 microstrain at 56 days).

Plant 21: Timaru

Aggregates were supplied by Allied Concrete in March 2002 and concrete cast during the same month.

Table 21.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Opihi River	13 mm and 19 mm gravel
Geological Type:	Greywacke	Greywacke
Colour:	Brown	Grey
Particle Shape:	Rounded	Rounded
Fineness Modulus:	2.69	-
Fines Content (%):	5.3	-
Relative Density:	2.65	2.65
10% FACT (kN):	-	315
Absorption (%):	-	0.73
Clay Index:	-	0.78
Intrinsic Shrink (με):	-	422

Fine aggregate was a well-grade river sand with moderate fines content. Coarse aggregate was river gravel with relatively high crushing resistance and moderate absorption.

Table 21.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m³):	2448	2417	2396
Comp. strength (MPa):	45.5	30.0	20.0
Split. strength (MPa):	4.2	3.2	2.6
Elastic modulus (GPa):	30.3	29.2	26.6
C.T.E. (με/K):	8.4	8.9	9.5
Shrinkage-56d (με):	836	761	714
Shrinkage-180d (με):	940	854	804
Effective porosity (%):	9.7	10.0	11.3

Plant 21 continued

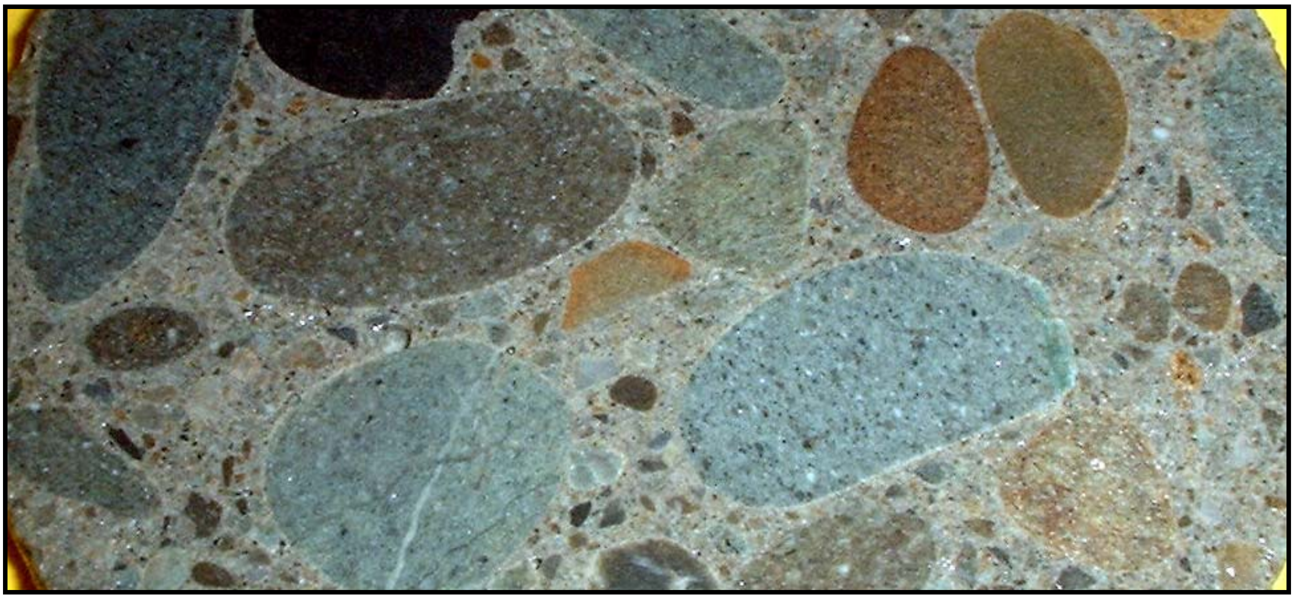

Figure 21: Concrete containing Timaru aggregates

Hardened concrete properties were within the normal range with the exception of thermal expansion and porosity, which were lower than expected. The presence of some limestone in the aggregate may have contributed to the lower coefficient of thermal expansion.

Plant 22: Oamaru

Aggregates were supplied by Firth Industries in January 2003 and concrete cast during the same month.

Table 22.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Natural pit	13 mm and 19 mm gravel
Geological Type:	Silica	Greywacke
Colour:	Golden	Grey
Particle Shape:	Rounded	Rounded
Fineness Modulus:	2.46	-
Fines Content (%):	8.5	-
Relative Density:	2.65	2.63
10% FACT (kN):	-	453
Absorption (%):	-	0.62
Clay Index:	-	0.67
Intrinsic Shrink (με):	-	305

Fine aggregate was pit sand with excellent grading and fines content. Coarse aggregate was river gravel having high crushing resistance and low absorption.

Table 22.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2345	2320	2305
Comp. strength (MPa):	38.5	25.0	19.8
Split. strength (MPa):	3.9	3.5	2.8
Elastic modulus (GPa):	35.5	33.0	31.5
C.T.E. (με/K):	10.4	10.3	10.5
Shrinkage-56d (με):	700	640	664
Shrinkage-180d (με):	830	745	766
Effective porosity (%):	12.1	12.4	13.0

Plant 22 continued

Figure 22: Concrete containing Oamaru aggregates

Concrete had moderate strength but high elastic modulus and relatively low drying shrinkage. Thermal expansion and porosity were within the normal range for structural concrete.

Plant 23: Queenstown/Wanaka

Aggregates were supplied by Firth Industries in April 2002 and concrete cast during the same month.

Table 23.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Clutha River	13 mm and 19 mm gravel
Geological Type:	Schist-greywacke	Schist-greywacke
Colour:	Brown	White-grey
Particle Shape:	Rounded	Elongated
Fineness Modulus:	2.56	-
Fines Content (%):	5.4	-
Relative Density:	2.65	2.68
10% FACT (kN):	-	140
Absorption (%):	-	0.80
Clay Index:	-	0.40
Intrinsic Shrink (με):	-	197

Fine aggregate was a well-graded river sand with a low fines content. Coarse aggregate was composite material containing greywacke and schist with a low crushing resistance.

Table 23.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2411	2344	2354
Comp. strength (MPa):	37.5	26.5	18.5
Split. strength (MPa):	3.2	3.1	2.2
Elastic modulus (GPa):	25.0	22.1	17.2
C.T.E. (με/K):	10.8	10.4	10.8
Shrinkage-56d (με):	643	676	647
Shrinkage-180d (με):	736	776	718
Effective porosity (%):	9.9	10.7	11.9

Plant 23 continued

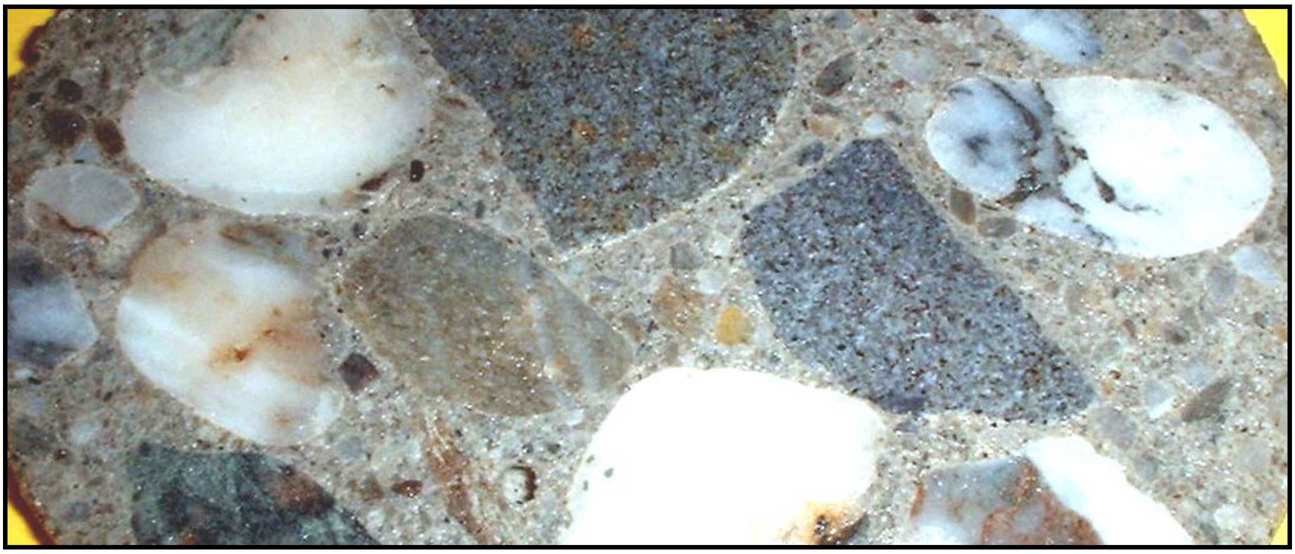

Figure 23: Concrete containing Queenstown aggregates

Concrete strengths were only moderate while elastic modulus values were relatively low. Thermal expansion values were quite high while drying shrinkage and effective porosity values were low.

Plant 24: Dunedin

Aggregates were supplied by Allied Concrete in September 2001 and concrete cast in November 2001.

Table 24.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Natural pit/Crusher	Crushed 13 mm and 19 mm
Geological Type:	Silica/Basalt	Phonolite
Colour:	Golden/Dark brown	Dark green
Particle Shape:	Rounded/Angular	Chunky
Fineness Modulus:	2.73/3.15	-
Fines Content (%):	6.2/9.0	-
Relative Density:	2.60/2.90	2.60
10% FACT (kN):	-	276
Absorption (%):	-	0.64
Clay Index:	-	-
Intrinsic Shrink (με):	-	95

Fine aggregate was a blend of natural and crusher sands with an overall fineness modulus of 2.90. Coarse aggregate was a crushed phonolite stone with moderate crushing resistance and low absorption.

Table 24.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2395	2399	2382
Comp. strength (MPa):	47.2	36.9	24.7
Split. strength (MPa):	4.0	3.4	2.7
Elastic modulus (GPa):	38.6	35.5	30.7
C.T.E. (με/K):	10.0	10.8	10.6
Shrinkage-56d (με):	583	511	543
Shrinkage-180d (με):	804	736	757
Effective porosity (%):	9.9	10.7	10.7

Plant 24 continued

Figure 24: Concrete containing Dunedin aggregates

Concrete strengths were relatively high while elastic modulus values were also higher than normal. Thermal expansion was slightly high but drying shrinkage and effective porosity values were low.

Plant 25: Manapouri

Aggregates were supplied by Meridian Energy in October 2001 and concrete cast in November 2001.

Table 25.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Tunnel spoil	Crushed 10 mm and 19 mm
Geological Type:	Gneiss-diorite	Gneiss-diorite
Colour:	Light grey	Grey-white
Particle Shape:	Angular	Angular
Fineness Modulus:	2.83	-
Fines Content (%):	10.5	-
Relative Density:	2.80	2.82
10% FACT (kN):	-	216
Absorption (%):	-	0.58
Clay Index:	-	-
Intrinsic Shrink (με):	-	105

Fine aggregate was a harsh crusher sand produced from tunnel spoil material. Coarse aggregate was an angular, crushed rock with moderate crushing resistance and low absorption. Slip plane of mica were present on many crushed surfaces.

Table 25.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2394	2399	2382
Comp. strength (MPa):	44.5	31.2	22.0
Split. strength (MPa):	3.9	3.3	1.9
Elastic modulus (GPa):	23.5	19.8	16.6
C.T.E. (με/K):	8.3	9.1	9.0
Shrinkage-56d (με):	750	690	586
Shrinkage-180d (με):	1019	964	861
Effective porosity (%):	11.8	12.6	12.5

Plant 25 continued

Figure 25: Concrete containing Manapouri aggregates

Concrete strengths were moderate due to the presence of muscovite and biotite, which are known to reduce strength. Elastic modulus values were low due to the presence of slip planes on aggregate surfaces. Thermal expansion, drying shrinkage and effective porosity were all within the normal range.

Plant 26: Invercargill

Aggregates were supplied by Allied Concrete in November 2001 and concrete cast in January 2002.

Table 26.1: Aggregate Properties

Type:	**Sand**	**Stone**
Source:	Oreti River	13 mm and 19 mm gravel
Geological Type:	Igneous-greywacke	Igneous-greywacke
Colour:	Brown-grey	Mixed
Particle Shape:	Rounded	Rounded
Fineness Modulus:	2.72	-
Fines Content (%):	9.8	-
Relative Density:	2.70	2.70
10% FACT (kN):	-	375
Absorption (%):	-	0.52
Clay Index:	-	0.33
Intrinsic Shrink (με):	-	180

Fine aggregate was a well-graded river sand with fairly high fines content. Coarse aggregate was a mixed gravel with high crushing resistance and low absorption.

Table 26.2: Hardened Concrete Properties (28 days unless noted otherwise)

Water/cement ratio:	**0.5**	**0.6**	**0.7**
Density (kg/m^3):	2437	2422	2426
Comp. strength (MPa):	37.5	31.0	25.5
Split. strength (MPa):	3.1	2.7	2.3
Elastic modulus (GPa):	38.3	35.4	31.4
C.T.E. (με/K):	10.0	10.5	9.7
Shrinkage-56d (με):	593	576	493
Shrinkage-180d (με):	764	761	693
Effective porosity (%):	9.6	10.3	9.6

Plant 26 continued

Figure 26: Concrete containing Invercargill aggregates

Concrete strengths were relatively low particularly tensile strength, which can be ascribed to the extremely smooth and rounded nature of coarse aggregate particles. Elastic modulus and thermal expansion were slightly higher than normal while drying shrinkage and effective porosity were relatively low.

Conclusions

Over a hundred concrete mixes were cast and tested during the two years of this research project. Not only was a diverse range of concrete materials tested, but results were found to vary considerably, reflecting the current usage of aggregates from high quality to more marginal resources. This research generated considerable data that required detailed analysis and synthesis to produce practical conclusions and recommendations. These are dealt with in more detail in other publications already in the public domain.

Aggregate properties of South Island materials and New Zealand greywacke aggregates are discussed in detail in New Zealand Concrete Society and ACI Materials Journal respectively[7,8]. General guidance and recommendations are given in these papers.

Early-age cracking of concrete and the specific influence of New Zealand aggregates is given in a paper for New Zealand Concrete Society[9]. Specific allowance for materials properties such as shrinkage, early thermal expansion, tensile strength and elastic modulus is given.

Hardened properties of concrete containing New Zealand aggregates are predicted based on analysis presented in SESOC Journal paper[10]. Estimates for material properties such as elastic modulus, coefficient of thermal expansion, drying shrinkage and fracture energy are discussed.

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