Kayasand concrete trial results

March 2024

KAYASAND
engineering sand for construction

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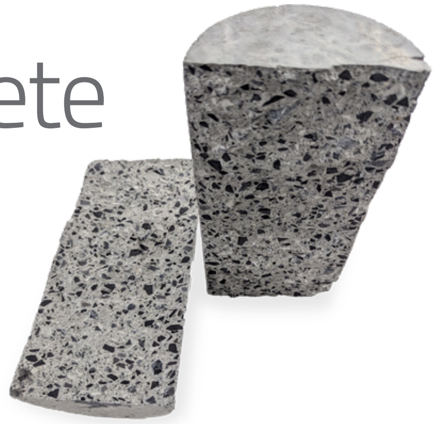


Kayasand's goal is to enable our customers to manufacture the ideal engineered sand for concrete. Manufactured sand is already widely used in concrete, but it is typically badly shaped, poorly graded and inconsistent leading to negative performance characteristics. Our testing shows that a quality engineered sand continuously manufactured by the Kemco V7 plant to precise specifications can outperform all other sands.

This document summarises concrete trial results using engineered sand from the Kemco V7 plant supplied by Kayasand. The trials were designed and carried out independently by James Mackechnie, a well-known concrete engineer in New Zealand. For these trials:

- The control is a standard 40MPa mix design using 60% manufactured sand and 40% natural sand.
- Two Kayasand materials were used (MS1 and MS2), both produced by Kemco V7 plants from different quarries in the Auckland region.
- The other raw materials, including manufactured sands and natural sands, were commonly available materials typically used in Auckland concrete mixes.
- Tests involve varying water to achieve a consistent target slump of 120mm.

The Kayasand process for manufacturing engineered sand for concrete ensures precise control of:

- Particle shape – Cuboidal with rounded edges.
- Sand grading / sizing – To optimise packing density
- Contamination – Removing clays and deleterious materials using a dry process.
- Consistency. – Achieving very consistence product over weeks and months.

Optimising these characteristics increases packing density and reduces water demand in concrete while maintaining workability. This enables concrete plants to lower cement levels while achieving the same strength.

The goals from these trials were to demonstrate the potential for Kayasand sand to:

- Replace 80-100% of natural sand in concrete;
- Reduce cement by 10%;

All while enhancing wet performance characteristics such as workability, pumpability and finish.

The results show consistent strength increases and 10% less cement requirements when using engineered sand for concrete produced from a Kayasand V7 plant. They also show complete replacement of natural sand in concrete is achievable using Kayasand V7 sand.

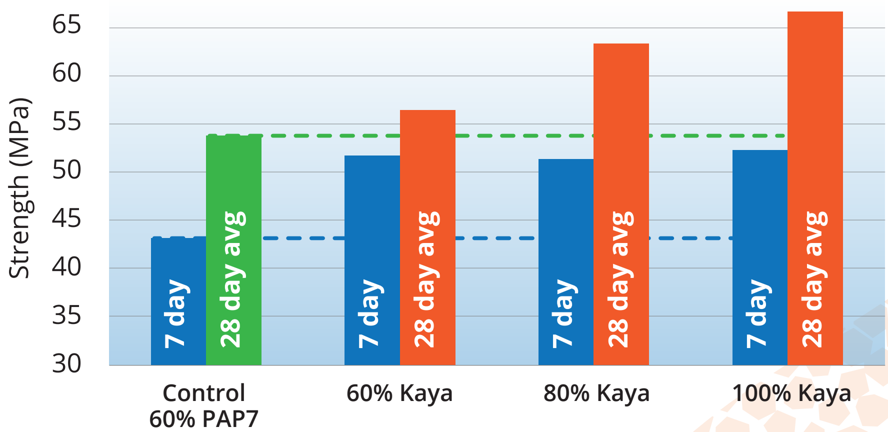
The economic and emissions savings from reducing cement and natural sand requirements in concrete are significant. Cement reduction could generate savings of over $10 per tonne of Kayasand V7 sand used. This is compared to the typical operating cost of our plants in the $4-5 per tonne range. Likewise, natural sand can be significantly more expensive than manufactured sand depending on availability. Whereas the V7 technology enables quality engineered concrete sand to be manufactured in quarries right alongside the coarse aggregate.

STRENGTH RESULTS GRAPHS

The report prepared by James Mackechnie is on the following pages. Below are charts of the strength results from these trials.

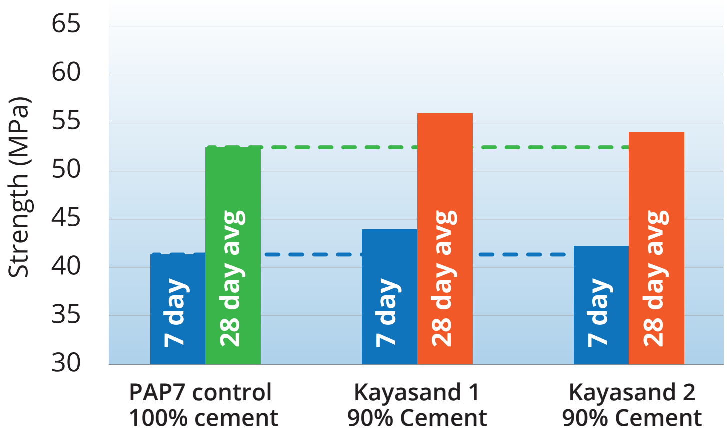
Concrete Lab Test 1

This first test looked at the impact on strength of using V7 engineered sand from Kayasand to replace varying amounts of natural sand in concrete from 60% to 100%. Less water was required for the mixes using Kayasand V7 sand, despite the mixes achieve higher slump. The results show the strength increased by 24% compared to the control when using Kayasand engineered sand as a 100% sand replacement.



Concrete Lab Test 2

This test looked at the impact of reducing cement content in mixes using Kayasand V7 sand. Workability was again maintained, with slump levels higher than the control. Despite using up to 10% less cement than the control, the results show concrete made using Kayasand V7 sand was still stronger.



Subject: Kayasand Laboratory at Auckland R&D Laboratory

A series of concrete mixes were produced using Auckland aggregates to assess the performance of an engineered sand made from Greywacke rock, supplied by Kayasand. This initial trial was run to compare the fresh and hardened performance of concrete in the laboratory. A standard 40 MPa 19mm pump mix was used as the control with normal Auckland aggregates (blend of PAP7 & offshore sand and crushed coarse aggregate). Details of the four concrete mixes are shown in Table 1 below.

Table 1: Concrete mix proportions used in the initial laboratory trial (Dec 2023)

Materials	K1 Control (60% PAP7)	K2 (60% Man Sand)	K3 (80% Man Sand)	K4 (100% Man Sand)
19mm Agg.	440	440	440	440
13mm Agg.	585	585	585	585
PAP7	485 KB07	0	0	0
Kayasand	0	485 Kemco	655 Kemco	820 Kemco
Sand	335	335	165	0
Holcim GP Cement	325	325	325	325
Holcim GGBS	85	85	85	85
Water reducer (Sika)	2900	2900	2900	2900
Water	187	173	170	172
Water/binder ratio	0.456	0.422	0.415	0.420
Predicted f_{28} (MPa)	49.9	54.2	55.1	54.5

Manufactured sand consisted of 95% pre-skimmer and 5% skimmer B (<0.075 mm of roughly 2.5% to match existing PAP7)

A series of concrete mixes were cast on Thursday 14th December in the R&D laboratory by the author.

Each concrete mix was a volume of 20L and mixed in a drum mixer for 5 minutes before adjusting with final trim water for a target slump of 120mm. Details of the fresh testing are shown in Table 2 with testing done in accordance with NZS 3112 Part 1.

Table 2: Fresh concrete properties measured on 40 MPa 19mm pump concrete – Initial trial

Properties	K1 Control (60% PAP7)	K2 (60% Man Sand)	K3 (80% Man Sand)	K4 (100% Man Sand)
Air temperature (°C)	18.5	18.0	17.5	18.0
Concrete temp. (°C)	19.8	19.2	19.0	19.2
Slump (mm)	100	110	120	130
Workability	Ok	Good	Ok	Ok
Bleed	Low	Very low	Very low	Low
Initial set (hr:min)	3:30	3:30	3:15	3:45

Three concrete cylinders were made from each mix for testing at 7 and 28 days in accordance with NZS 3112 Part 2 (see Table 3 below). Hardened density is also reported as this provides information about workability since better compaction is usually achieved when concrete is more workable.

Table 3: Hardened density and compressive strength of concrete cylinders after standard wet curing

Age (days)	Property	K1 Control (60% PAP7)	K2 (60% Man Sand)	K3 (80% Man Sand)	K4 (100% Man Sand)
7	Hard. Density (kg/m^3)	2430	2430	2450	2456
	Comp strength (MPa)	43.3	51.9	51.6	52.4
28	Hard. Density (kg/m^3)	2441	2446	2451	2460
	Comp strength (MPa)	52.1	58.4	65.3	65.1
28	Hard. Density (kg/m^3)	2433	2438	2458	2465
	Comp strength (MPa)	55.8	54.6	61.9	68.5

Second trials completed in January 2024

A further set of six concrete mixes were cast on 16th & 17th January in the R&D laboratory that investigated the benefit of using Kayasand products in terms of potential cement savings. Details of the six concrete mixes trialled are shown in Table 4 below.

Table 4: Concrete mix proportions used in the second laboratory trial (Jan 2024)

Materials	K1RP Control (60% PAP7)	K2A (60% MS1, 95% Cem.)	K2B (60% MS1, 90% Cem)	K3A (80% MS1 95% Cem)	K3B (80% MS1. 90% Cem)	K3C (80% MS2 90% Cem.)
19 mm Agg.	440	460	460	475	475	475
13 mm Agg.	585	585	585	585	585	585
PAP7	485 ^{PAP7}	0	0	0	0	0
Kayasand	0	485 ^{MS1}	485 ^{MS1}	655 ^{MS1}	655 ^{MS1}	655 ^{MS2}
Sand	335	335	335	165	165	165
GP cement	325	309	292.5	309	292.5	292.5
Holcim slag	85	81	76.5	81	76.5	76.5
WR (Sika)	2900	2900	2900	2900	2900	2900
Water	190	177	175	178	175	170
w/b ratio	0.463	0.454	0.474	0.456	0.474	0.461
Predict f_{28}	49.0	50.1	47.8	49.9	47.8	49.3

Manufactured sand consisted of 90.6% pre-skimmer and 9.4% skimmer B (<0.075 mm of 5% to match Kayasand ideal grading) MS1 denotes pre-skimmer sand (Jan 2024), MS2 denotes V7-40 Ward sand that was pre-blended by Kayasand

Each concrete mix was a volume of 15L and mixed in a drum mixer for 5 minutes before adjusting with final trim water for a target slump of 120mm. Details of the fresh testing are shown in Table 5 with testing done in accordance with NZS 3112 Part 1.

Table 5: Fresh concrete properties measured on 40 MPa 19mm pump concrete – Second trial

Property	K1RP	K2A	K2B	K3A	K3B	K3C
Air temp	27.0	27.0	26.5	25.5	25.8	25.5
Conc. Temp	26.5	27.0	27.2	27.0	26.5	26.5
Slump	120	145	140	150	135	130
Workability	Ok	Good	Good	Good	Ok	Ok/Good

Three concrete cylinders were made from each mix for testing at 7 and 28 days in accordance with NZS 3112 Part 2 (see Table 6 below). Hardened density is also reported as this provides information about workability since better compaction is usually achieved when concrete is more workable.

Table 6: Hardened density and compressive strength of concrete cylinders after standard wet curing

Age (days)	Property	K1RP	K2A	K2B	K3A	K3B	K3C
7	HD (kg/m^3)	2447	2451	2439	2453	2439	2435
	f_c (MPa)	41.5	49.6	43.9	42.7	44.1	42.2
28	HD (kg/m^3)	2439	2444	2451	2439	2436	2417
	f_c (MPa)	54.1	62.2	58.4	52.1	55.4	54.9
28	HD (kg/m^3)	2436	2455	2445	2437	2445	2411
	f_c (MPa)	51.0	59.9	55.8	58.9	56.7	53.4

Indications from 28-day strength results are that replacement of standard PAP7 with Kayasand products can produce a cementitious saving of at least 10% without compromising strength. The improved strength performance of concrete made with Kayasand (MS1 & MS2) appears to be a combination of reduced water demand and improved packing resulting in higher density.

"Engineered sand is a viable replacement for natural sand in concrete and significantly contributes to the industry hitting their carbon emissions target by 2050."

— **James Mackechnie** CPEng, PhD

James started in construction working on a tunnel, being involved in the concrete batching and pumping. This was followed by five years working as a structural engineer in Zimbabwe and South Africa before specialising in concrete technology with a PhD from the University of Cape Town.

As a post-doctoral researcher, James was involved in condition surveys of infrastructure as well as research on durability and repair of concrete structures.

He moved to New Zealand in 2001 and spent seven years at the University of Canterbury as CCANZ Fellow/Senior Lecturer involved in a wide range of teaching and research.

James is also an Adjunct Senior Fellow at the University of Canterbury where his office is based. James has a passion for teaching, and is keen to help inspire others to achieve a deeper understanding of concrete's potential.