Increasing the use of supplementary cementitious materials (SCMs) in concrete production in New Zealand

With New Zealand committed to achieving a net-zero carbon economy by 2050, the pressure is on to find ways of reducing greenhouse gas emissions in the construction industry and the built environment. Replacing 30% of the Portland cement in concrete with supplementary cementitious materials (SCMs) could reduce the embodied carbon in concrete by as much as 20%.

While concrete offers buildings benefits, such as strength, durability, thermal mass and fire resistance, it is also a contributor to the embodied carbon footprint of many structures. This mainly comes from the production of Portland cement (the binding agent in concrete) where limestone and other ingredients are heated at very high temperatures. Approximately, 35% of the carbon dioxide emissions come from the fossil fuels and 65% from the decomposition of limestone.

One approach to reducing emissions is to change how Portland cement is manufactured - for example, by changing the type of fuel used. This is happening around the world, including in New Zealand. Significant benefits can also be found in replacing cement clinker with supplementary cementitious materials (SCMs).

International research has focused on recycled SCMs produced from heavy industry such as slag from blast furnaces. OECD countries with a strong heavy industry sector have adopted significant levels of SCMs in concrete. The SCM component in New Zealand concrete is relatively low in comparison because of the relative absence of heavy industry here.

What New Zealand does have in sizeable quantities are SCMs such as natural pozzolans, including varieties of volcanic glass, silica and pumice that are often found in volcanic regions.

There are big differences between SCMs. For example ground granulated blast-furnace slag can replace up to 70% of Portland cement in a concrete mix, while silica fume (also from heavy industry) is rarely used at more than 10% replacement because of its effect on the workability of fresh concrete.

To classify SCMs, an experimental research programme initiated in early 2020 was undertaken at the University of Canterbury with some funding provided by the Building Research Levy. It investigated materials and test methods and compared performance with international norms and standards. This fact sheet gives a brief overview of the findings. BRANZ External Research Report ER66 *Removing the barriers to the use of significant levels of SCMs in concrete production in New Zealand* gives more details.

Research with SCMs

The experimental work used a range of Portland cements and recycled and natural

SCMs from local and overseas sources. A series of SCM concrete were assessed against a control concrete using 100% Portland cement as the binder.

Fresh concrete properties were assessed for:

- slump
- bleed
- setting
- workability.

Hardened concrete properties were assessed for:

- density
- compressive strength
- porosity
- oxygen permeability
- accelerated carbonation
- chloride resistance
- expansion induced by alkali-silica reaction (ASR).

Concretes that contain SCMs can take longer to set and gain compressive strength than concrete with 100% Portland cement as binder. However, replacement of 30% or more of the Portland cement with SCMs can achieve good strengths and superior durability properties in some cases (Table 1).

Concrete containing natural pozzolans or calcined clay showed reasonable strength performance and good durability potential comparable with established SCMs such as fly ash and slag. Pumice was found to produce relatively promising results in terms of strength development when ground very fine. (Earlier research found it gave equivalent strength to Portland cement concrete after 90 days but early-age strength development was slower.)

Finer SCMs such as calcined clay and silica fume are most effective in concrete with lower water/binder ratios that achieve higher compressive strength. Fly ash in concrete was more effective in lower-strength grades since workability was not negatively affected by water demand issues.

Replacing 30% of the Portland cement in concrete with SCMs was calculated to have the potential of reducing embodied carbon by as much as 20% in several cases

Fresh properties of concrete

The research found that the workability of fresh concrete varied depending on the SCM used, but this was not significant and can be allowed for by adjusting materials and admixtures. The research confirmed what other research had found - increasing percentages of SCMs in concrete reduces bleeding and extends the setting time. Plastic shrinkage cracking may occur when using SCMs in concrete unless mixes are optimised and sitework follows sensible construction practice.

Table 1. Summary of benefits and risks using SCMs in concrete.

ISSUE	RISKS OR BENEFITS	ADJUSTMENTS
Lower bleeding	Plastic shrinkage	Protection from rapid drying
Delay in setting time	Exacerbated in winter conditions	Use of set accelerators
Strength development	Lower early strength	Improved long-term strength
Carbonation resistance	Reduced especially if curing is poor	Improved curing and mixes
Chloride resistance	Generally improved	Correct SCM classification
Alkali-silica reaction	Reduced expansion risk	Correct SCM classification
Sustainability	Up to 20% lower embodied carbon	Benefit depends on SCM reactivity

Strength development

Replacement of Portland cement with SCMs reduces early strength development of concrete but improves long-term strength development.

The testing age for concrete is typically at 28 days or less, which tends to favour more-reactive SCMs and often means that natural pozzolans are excluded on the basis of their comparatively slower strength development.

Finer SCMs such as calcined clay and silica fume were found to be most effective in concrete with lower water/binder ratios that achieve higher compressive strength.

Durability

Adding SCMs to concrete generally improves its microstructure, producing a more durable structural material. This research found a general improvement in most cases but specific durability performance depended on the SCM used (Table 2). Promising durability came from more-reactive SCMs such as fly ash, ignimbrite, calcined clay and silica fume. Slag is well known for improving the durability of concrete. Concretes using SCMs were shown to consistently lower porosity and permeability, which should also improve resistivity and chloride resistance. All SCMs showed a beneficial effect in reducing expansion associated with alkali-silica reaction although some materials were more effective than others long term.

All SCM concretes were found to have lower carbonation resistance compared with concrete containing 100% Portland cement regardless of the curing regime. Carbonation does not pose a durability problem for concrete itself, but it can lead to the corrosion of reinforcing steel. The generally superior hardened properties of SCM concrete with regards to penetrability and resistivity are expected to assist in reducing reinforcement corrosion rates.

Predictability is key

It is estimated that current replacement levels of Portland cement with SCMs in New Zealand are below 5%. This research focused on technical barriers, which can be significant given the conservative nature of design and construction. It should be remembered that SCMs are used extensively in other countries.

The research found that the test method in AS 3583.6 *Methods of test for supplementary cementitious materials - Method 6: Determination of relative water requirement and strength index* is unable to accurately predict the reactivity of SCMs, especially natural pozzolans (Table 3). It recommends that NZS 3123:2009 *Specification for pozzolan for use with Portland and blended cement* be revised and alternate classification systems be adopted. This research confirmed that there are internationally recognised methods that can predict performance.

Practical considerations

The performance of SCM concretes can be accurately predicted provided a rational classification system is used when assessing these materials.

Table 2. Qualitative assessment of the durability performance of different concrete mixes (90 days).

DURABILITY PROPERTY	H1/H11 100% GP	H2/H12 30% FAG	H3/H13 30% FAH	H4/H14 30% Pozz.	H5/H15 30% Perl.	H6/H16 30% CC	H7/H17 8% CSF	H8/H18 100% HE	H9/H19 HE 30% FAH	H10/H20 HE 30% Pozz.
Porosity	2	3	2	2	3	1	1	2	2	2
Oxygen permeability	2	2	2	2	2	1	1	2	1	2
Accelerated carbonation	2	3	3	3	4	2	2	1	2	2
Resistivity	2	2	2	1	2	1	1	2	1	1
Chloride resistance	4	3	2	2	4	1	1	3	3	3
ASR expansion	5	3	1	1	2	1	-	-	-	-

- H1=100% general purpose Portland cement; H2=30% Huntly fly ash; H3=30% Adani fly ash; H4=30% pozzolan; H5=30% perlite; H6=30% calcined clay; H7=7% silica fume; H8=100% high early strength cement control. (H1–H10 GBC cement; H11–H20 Holcim cement.)
- 1 – very good, 2 – good, 3 – moderate, 4 – moderate/poor, 5 – poor.

Replacing Portland cement with significant amounts of SCMs may affect the setting time of the concrete. It may be that the specification of the concrete will require a chemical admixture to speed up the setting to meet target construction timeframes.

Maximising the benefits from SCMs requires good site practice, but the potential savings in carbon by using them makes the case for SCMs extremely compelling.

More information

BRANZ External Research Report ER66 [2021] *Removing the barriers to the use of significant levels of SCMs in concrete production in New Zealand*

Table 3. Comparison of classification systems for SCMs in concrete.

CLASSIFICATION METHOD	STANDARD OR REFERENCE	ADVANTAGES	LIMITATIONS	CORRELATION WITH CONCRETE STRENGTHS
Relative strength	AS 3583.6	Simple equipment well established	Water demand variable, which affects water/binder ratio	Poor (R^2 = 0.003)
Modified strength activity index	EN 196-1 (constant water/ binder ratio)	Simple equipment easy adjustment	Requires careful dosing and testing	Good (R^2 = 0.87)
Isothermal calorimetry	EN 196-8 2010	Quick and very accurate	Specialist test equipment – expensive	Good (R^2 = 0.89)
Bound water analysis	Avet et al[1]	Accurate and easy with correct gear	Specialist test gear – moderate costs	Very good (R^2 = 0.93)

1. Avet, F., Snellings, R., Diaz, A. A., Haha, M. B. & Scrivener, K. (2016). Development of a new rapid, relevant and reliable (R^3) test method to evaluate the pozzolanic reactivity of calcined kaolinitic clays. *Cement and Concrete Research*, *85*, 1–11.