Supplementary Cementitious Materials

This factsheet advises on the use of supplementary cementitious materials in low carbon concrete.

Fly ash

Fly ash (FA) is a pozzolan, by-product of coal burning in power plants.

Suitable use: Structural concrete, non-structural concrete, concrete pavement, pavement base and subbase.

Benefits of fly ash

- Good workability and pumpability
- Higher ultimate strength
- Improved resistance to chloride ingress
- Alkali–silica reaction (ASR) mitigation (minimum 20-25% replacement)
- Reduced heat of hydration and risk of early age thermal cracking
- **Embodied carbon:** Fly ash is in the range of 14-27 kgCO2e/kg compared to ~970 kgCO2e/tonne for Original Portland Cement (OPC).[1]

Considerations for fly ash

Durability

- Can impact carbonation resistance, but additional cover or coating can mitigate the risk.

Program

- Can have slower setting time and slower strength development, but modern admixtures can address this issue.

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Implications for fly ash

Designer/ specifier

- Requires accelerators to achieve high early age strength requirements.
- For replacement levels above 35%, additional cover may be needed to protect external elements at risk of carbonation.
- For precast and prestressed concrete, replacement levels to achieve strength development requirements must be determined and selected.
- Specifier must understand performance requirement, such as early age strength, or heat of hydration.
- AS3600 is silent, however there is no restriction to the application.
- Fly ash may be required for certain exposure conditions as per AS5100.

Construction team

- Setting and curing times can be increased if accelerators not used.

Ground granulated blast furnace slag

Ground granulated blast furnace slag (GGBFS) is a by-product of iron smelting and is grounded to suitable fineness.

Suitable use: Structural concrete, non-structural concrete, concrete pavement, pavement base and subbase.

Benefits of ground granulated blast furnace slag

- Improved resistance to sulfate attack.
- Higher ultimate strength.
- Alkali–silica reaction (ASR) mitigation (minimum 50% replacement).
- Reduced heat of hydration and risk of early age thermal cracking.
- **Embodied carbon:** GGCFS is in the range of 130-192 kgCO2e/kg compared to ~970 kgCO2e/tonne for Original Portland Cement (OPC).[1]

Considerations for ground granulated blast furnace slag

Durability

- Can impact carbonation resistance, but additional cover or coating can mitigate the risk.

Program

- Can have slower setting time.
- Can have slower strength development if accelerators are not used.

Implications for ground granulated blast furnace slag

Designer/ Specifier

- Requires accelerators to achieve high, early age strength requirements.
- For replacement levels above 60%, additional cover may be needed to protect external elements at risk of carbonation.
- For precast and prestressed concrete, select replacement levels that meet strength development requirements.
- Specifier to understand performance requirement, such as early age strength, heat of hydration.
- AS3600 is silent, however there is no restriction to the application.
- Ground granulated blast furnace slag may be required for certain exposure conditions as per AS5100.

Construction team

- Can increase setting and curing time if accelerators not used.

Silica fume

Silica fume is a by-product of the smelting process used in producing silicon and ferrosilicon alloys. This material is finer than cement.

Suitable use: Structural concrete, non-structural concrete, shotcrete applications, concrete pavement, pavement base and subbase.

Benefits of silica fume

- Higher early and long-term strength.
- Improved abrasion resistance.
- Improved chemical resistance (low permeability).
- Alkali–silica reaction (ASR) mitigation (minimum 8% replacement).
- Reduces concrete bleeding.
- Used in ternary mixes with fly ash or GGBFS to improve durability.
- Typically, 3-10% replacement of cement.
- **Embodied carbon:** Silica fume is typically similar to fly ash.

Considerations for silica fume

Durability

- Can impact carbonation resistance, but additional cover or coating can mitigate the risk.

Implications for silica fume

Designer/ Specifier

- For high replacement levels, additional cover may be needed for external elements at risk of carbonation.
- Can require more water due to its fineness, but an adequate mix design would enable compliance with the fresh property requirements.

Construction team

- Can decrease workability and finish-ability if high replacement amounts are used and admixtures are not specified.

Calcined clay /metakaolin

Calcined clay often consists of clay heated to a temperature between 650ºC and 850ºC. metakaolin is the most commonly available calcined clay on the international market.

Calcined clay is not currently readily available in the Australian market. Suppliers, universities and others in the industry are collaborating to bring it to the market in Australia.

Benefits of calcined clay, also known as metakaolin

- No changes in setting times.
- Decreased heat of hydration.
- Increased finish-ability.
- Increased early and long-term strength.
- Improved chemical resistance (low permeability).
- Alkali–silica reaction (ASR) mitigation.
- For Metakaolin, typically, up to 10% replacement of cement.
- **Embodied carbon:** Calcined clay is ~16-24% of the embodied carbon of an OPC. Note that calcined clay is not yet readily available in Australia, however this is expected to change over the coming years.

Considerations for calcined clay, also known as metakaolin

Durability

- Can impact carbonation resistance, but additional cover or coating can mitigate this risk.

Implications for calcined clay, also known as metakaolin

Designer/ Specifier

- For high replacement levels, consider adding extra cover to protect external elements at risk of carbonation.
- Can require more water due to its fineness, but an adequate mix design would enable compliance with the fresh property requirements.

Application of supplementary cementitious materials (SCMs) in concrete

The below table outlines the application of SCM in concrete in NSW.

Blends	Replacement levels		
	Traditional usage	**To be used on projects**	**Ambitious targets**
Binary blends: Fly ash + General Purpose (GP) **cement**	Fly ash: 10-25% (Overall 10-25% embodied carbon savings)	Fly ash: 35% cast in situ 30% precast and prestressed (Overall 30-35% embodied carbon savings)	Fly ash: >35% (>35% embodied carbon savings)
Binary blends: Slag + General Purpose (GP) cement	Slag: 30%~50% (Overall 25-40% embodied carbon savings)	Slag: 50% (overall) (~40% embodied carbon savings) 60% cast in situ 45% precast and prestressed	Slag: >70% (>55% embodied carbon savings)
Tertiary blends: Fly ash + Slag + General Purpose (GP) **cement**	Fly ash + Slag: 20-30%	Fly ash + Slag: 25% + 25% (or 20% plus 30 %) **A range of combinations are possible**	Fly ash + Slag: 50-65% **A range of combinations are possible**

Observations	No impact to early age performance requirements.	• Minor or no reductions for 1 to 5 days concrete strength. • No negative impact on 28 days strength • Cost neutral if minor early age strength reductions can be accommodated (minor cost impacts if no early age strength reductions permitted).	• 1 to 5 days strength reduction. • No negative impact on 28 days strength • Cost increase if higher early age strength is required. • Longer curing (>7 days) • Increased carbonation risk may require additional cover if exposed to the atmosphere and moisture
Implementation actions	No extra actions are required.	• Include replacement levels and maximum cementitious content in concrete specification. • Engage with local suppliers two months in advance so they can ensure local plants can accommodate requirements. • Contractor can use either high performance low shrinkage concrete, high early age concrete or lower performance concrete with slight early age strength reduction. • Concrete supplier to provide verification documents demonstrating compliance with the designer's requirements	• Include replacement levels and maximum cementitious content in concrete specification and drawings. • Engage with local suppliers two to four months in advance so they can identify if trials are required and to ensure local plants can accommodate requirements. • Authority approval for infrastructure projects is typically required to demonstrate compliance with performance requirements against authorities' concrete specification (such as RMS B80) or Australian Standards (such as AS3600, AS5100).

		(such as compressive strength, early age strength, and performance in certain exposure conditions etc), % of SCM replacement, concrete mix design (including admixtures and accelerators).	• Inform construction team on the possible impact of early strength delay. • Concrete supplier to provide verification documents demonstrating compliance with designer's requirements, % of SCM replacement, concrete mix design.

Future pathways for supplementary materials in concrete

Technology	Main components	Status	Supply chain
High SCMs concrete mixes	Black coal fly ash and slag	Easy wins, available now, temporary solution.	Subject to local fly ash supply. This material will be available until the closure of coal-fired power stations between 2028 – 2048. Slag mostly sourced from Japan. Port Kembla slag is also available in NSW.
Pond ash	Mixture of black coal fly ash and bottom ash which is collected in ash ponds	Researched but not field trialled.	Major concrete suppliers and NSW Government are conducting research and establishing the supply of pond ash. Supply and use expected to be available after the closure of coal-fired power stations between 2028 – 2048.
Geopolymer concrete or Geopolymer with GFRP bars	Black coal fly ash	Researched and field trialled. SA TS 199:2023 provides requirements and guidance for the design and construction of geopolymer concrete (GPC) and alkali-activated binder concrete (AABC) building structures and members that contain	Subject to local fly ash supply. This material will be available until the closure of coal-fired power stations between 2028 – 2048. Limited suppliers.

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		reinforcing steel or tendons, or both.	
Alkali activated concrete	Slag	Researched and field trialled. SA TS 199:2023 provides requirements and guidance for the design and construction of geopolymer concrete (GPC) and alkali-activated binder concrete (AABC) building structures and members that contain reinforcing steel or tendons, or both.	Subject to slag availability. Suppliers are currently performing trials. Limited suppliers.
Geopolymer concrete (calcined clay based)	Calcined clay[1]	Researched but not field trialled.	Major concrete suppliers are conducting research and establishing the supply of calcined clay. Supply expected to be available in 5 years
Concrete with pozzolans cement replacement (calcined clay based)	Calcined clay	Researched but not field trialled.	Major concrete suppliers are establishing the supply of calcined clay. Supply expected to be available in 5 years.
Concrete with calcined Clay Cement LC3[2]	Calcined clay, clinker and limestone	Researched but not field trialled.	Major concrete suppliers are conducting research and establishing the supply of calcined clay. Supply expected to be available in 5 years.

Note:

1. Calcined clay, also known as Metakaolin, is produced by heating kaolin, which is a widely available natural clay mineral, to a temperature between 650°C and 800°C.

2. Approximately 30% calcined clay, 50% clinker, 20% limestone.

[1] Greenhouse gas intensity factors based on AusLCI (V1.42). See ‘How to calculate embodied carbon of a concrete mix of a concrete mix’ Fact Sheet for further details.