Reducing CO_2 emissions through cement grinding optimisation

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This article looks at the various methods available to help lower the clinker factor in cement, what issues need to be considered in each case and their potential impact on CO_2 emissions.

Cement is the world's most prevalent man-made material, with some 2m³ of concrete produced for every inhabitant. With such a large volume, it is not surprising that every aspect of manufacture has potential for major impacts, economically, environmentally and otherwise. The industry has a long history of continuous improvement, including in areas such as energy efficiency, alternative fuels, and abatement of SO_x, NO_x and dust. One frequently-discussed issue is carbon dioxide emission. Sustainable development is taken very seriously, as indicated by support for the World Business Council for Sustainable Development (WBCSD) Cement Sustainability Initiative (CSI).[1]

Cement manufacture accounts for a significant part of manmade CO_2 emissions and many manufacturers have made public commitments to significantly reduce net CO_2 emissions, with reduction protocols established and legislation in place worldwide, including CO_2 taxes and emission trading schemes.

The majority of CO_2 arises during clinker production, due to the calcination of calcium carbonate, fossil fuel burning and electricity consumption (mostly for grinding). Approximately, each tonne of Portland cement clinker requires 1.25t of limestone, which accounts for 0.5t of CO_2 release during calcination. Primary energy, when mostly supplied from fossil fuels, releases 0.2-0.5t of CO_2 (depending on fuel and process type and efficiency). Thus each tonne of clinker has an associated 0.7-1t of CO_2 (the CSI CO_2 protocol adopts a default value of 0.862t CO_2/t of purchased clinker). Electricity consumption adds another 0.05-0.15t of CO_2 (depending on total kWh/t and the fuel source for electricity generation).

CO_2 reduction measures

CO_2 reduction initiatives are being increasingly implemented, and their application and diversity will increase as the cost of CO_2 increases.[2] There are a number of approaches to reducing cement's carbon footprint and some are already highly developed, such as increased energy efficiency (lower GJ/t) from process optimisation, utilisation of waste heat, alternative/waste fuels (zero carbon rated), decarbonated raw materials, mineralisation,[3] reduced tri-calcium silicate content and increased amount of supplementary cementitious material (SCM) in cement (lower clinker factor).

Lower cement grinding energy consumption

While many efforts have concerned the kiln and fuels, optimisation of grinding can also play a significant role in cutting CO_2. Energy consumption can be reduced by mill system design and optimisation, selection of cement grade and by improving grindability. However, the use of quality-enhancing chemical process additives or quality improvers (QI) can improve hydration and thus directly allow clinker factors to be reduced without adversely affecting product quality.

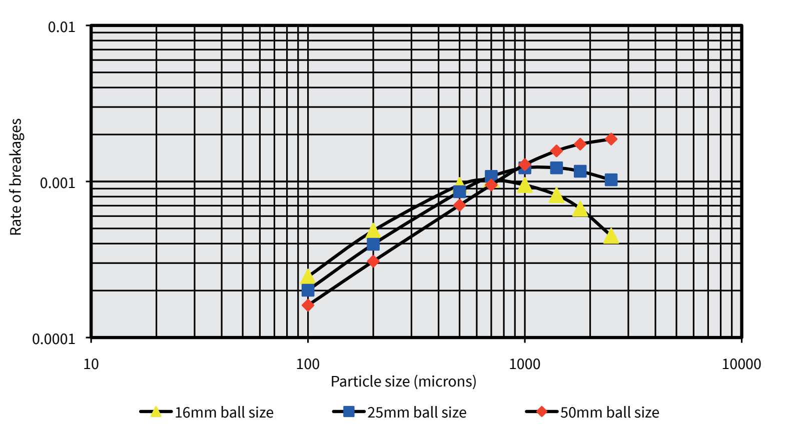
Cement grinding typically consumes 20–70kWh/t and depends upon a number of factors, including mill system type/design and operating characteristics, cement fineness level, cement composition (clinker, SCM, gypsum amounts) and material grindabilities (principally resulting from clinker and SCM levels). In over 300 audits of ball mill systems provided by Grace, the average mill-only power consumption was around 37kWh/t, rising to approximately 40-50kWh/t for the full mill systems. The CO_2 attributed to producing a unit of electric power is a function of the fuel used and conversion efficiency of generation, which varies around the world according to the current mix of coal/gas/hydro/renewable/nuclear sources. CO_2 emissions can range from 0.1 to almost 1kg/kWh generated, depending on the supply mix. Thus the CO_2 emissions for 45kWh/t consumed for cement grinding is around 5-40kg. The figure for mixed-fuel source electricity generation emitting 0.5kg/kWh[4] would be ~23kg.

As discussed in the article by Lawrie Evans, much cement is still ground in ball mills, although there is a large range of alternative systems that can operate for equivalent conditions at around 75 per cent of the kWh/t of a ball mill system. Also, there are a variety of approaches that can improve output and reduce kWh/t for existing ball mills. These include:

- separator design (eg conversion to third generation technology)[5]
- mill internals and ball charge optimisation (eg smaller second chamber mean ball size)[6]
- process control/optimisation (eg optimised circulating load and automated mill control)
- grinding aids (providing de-agglomeration, de-coating, improved dispersion and reduced mill filling).[7]

These can often achieve up to a 20 per cent increase in output and perhaps 10-15 per cent saving in total kWh/t. Reductions of indirect CO_2 emissions of 2-4kg/t of cement can

Figure 1: relationship between particle size and breakage rate for ball sizes



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therefore be envisaged for non-optimised ball mill circuits. Switching to a system with a more efficient mill can be expected to consume only 75 per cent of the ball mill kWh/t, ie 11-12kWh/t less, with an associated CO_2 reduction of 5-6kg/t of cement.

The most significant lever for reduction of CO_2 emissions during cement grinding is to lower the clinker factor.

The ability to reduce cement fineness provides immediate benefits to mill output and kWh/t reductions. In approximate terms a 10m²/kg reduction in Blaine (ie Blaine equivalent for CEM I, allowing for the different influences of SCM, gypsum, etc) can reduce energy consumption by some 1-2kWh/t and hence save 0.5-1kg CO_2/t of cement. Cement performance requirements, material quality (principally clinker) and particle size distribution govern the scope for reducing fineness. As a guide, an increase of 1MPa above target at 28d could allow a 20m²/kg reduction in Blaine and hence of 2-4kWh/t and 1-2kg CO_2/t of cement.

The grindability of feed materials varies widely and directly influences the kWh/t required for specified fineness and quality levels. Limestone, fly ash and pozzolan contribute to measured Blaine more than clinker, but provide less strength performance per m²/kg. Slag usually provides a lesser contribution to both Blaine and strength per kWh/t. Clinker grindability is generally the most significant factor and can surprisingly vary by as much as 50 per cent, eg, due to alite/belite ratio, sulphate content, porosity, microstructure (due to raw material preparation, burning degree and cooling) and granulometry. Optimising clinker properties can yield significant benefits for quality and mill output and provide important reductions in kWh/t and associated CO_2 emissions – perhaps by as much as 5-6kg/t of cement.

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Lowering the cement clinker factor

Not surprisingly cement clinker content largely correlates with the CO_2 emitted per tonne. Using a base CO_2 factor of 862kg CO_2/t clinker, each one per cent drop in clinker factor can reduce emitted CO_2 by 8-9kg/t cement.

The utilisation of materials such as blast-furnace slag, fly ash, pozzolan and limestone in cement, has been practised for many years on the basis of market needs, availability and economic attractiveness. Interest in SCMs is further increasing as an economic means to reduce CO_2 emissions.

However, increasing the SCM level to lower the clinker factor usually results in somewhat poorer cement performance. For example, although slower early-strength development is most commonly the limiting factor, each one per cent increase in SCM can reduce 28-day mortar strength by some 0.2–0.8MPa, depending on many factors, such as SCM type, fineness, mill system, clinker characteristics, etc. Increasing the level of clinker replacement and still maintaining market

Table 1: implied emission factors from electricity generation

Fuel	gCO_2/kWh
Anthracite*	920
Coking coal*	780
Other bituminous coal	860
Sub-bitiminous coal	920
Lignite	990
Coke oven coke*	770
Coal tar*	720
BKB/peat briquettes*	800-1500
Gas works gas*	420
Coke oven gas*	420
Blast furnace gas*	2200
Other recovered gases*	2000
Natural gas	400
Crude oil*	630
Natural gas liquids*	480
Refinery gas*	400
Liquefied petroleum gases*	500
Kerosene*	650
Gas/diesel oil*	690
Fuel oil	670
Petroleum coke*	1000
Peat*	750
Industrial waste*	400-2000
Municipal waste (non-renewable)*	450-3500

*Fuels represent less than 1% of electricity output in the OECD. Values will be less reliable and should be used with caution.

Source: Reference [4]

Figure 2: average grindability curve

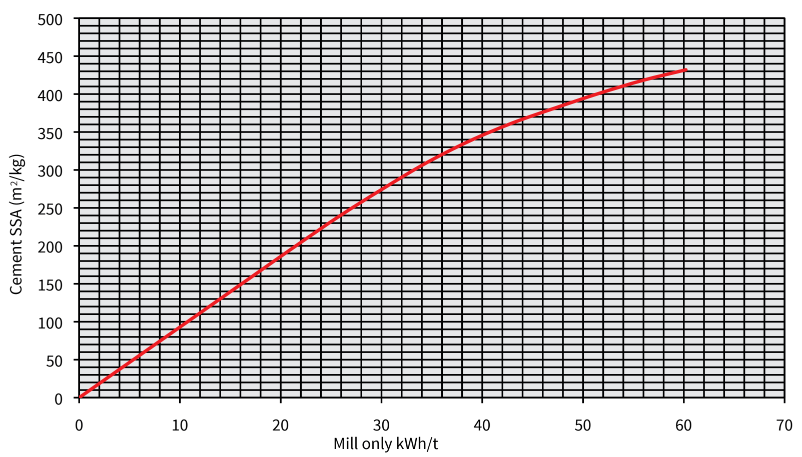
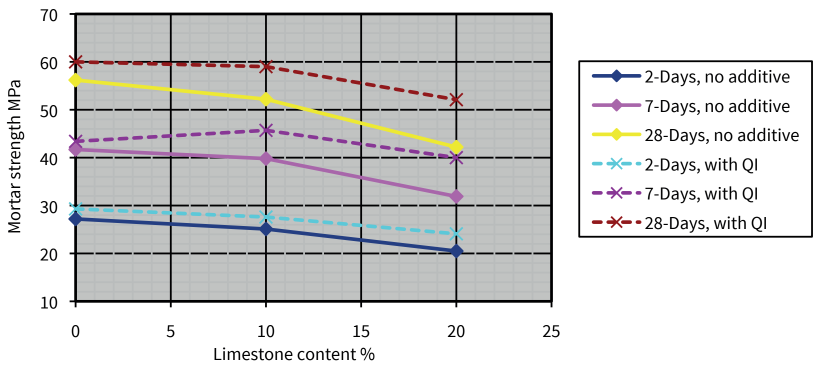


Figure 3: influence of limestone content on mortar strength – no additive and with quality improver (QI)



acceptance can be significantly assisted by an increase in cement performance, for example by increased clinker quality, increased cement fineness or by appropriate application of a chemical additive.

Increasing clinker quality requires full consideration of the effects of all production factors, including chemical and physical properties and process operation. Raising LSF (hence C_3S) is often practised but must be balanced against impacts on burning regime and microstructure. Mineralisation has facilitated raised C_3S levels with some success. A strength increase of 1MPa can be expected to allow a 1-2 per cent reduction in clinker factor for equal performance and thus provide a reduction of 8-17kg CO_2/t of cement.

A ready alternative to changing base clinker quality is to use a cement performance additive.[8] These are compounds that, when integrated into the cement manufacturing process, allow cement producers to increase the output and efficiency of grinding and significantly improve the performance, quality and handling of the finished cement, thereby allowing an increase in cement productivity and profitability. Whilst the principal advantage of such additives is to create economic gain from lower cement compositional costs, increased output and increased cement volume per tonne of clinker, they can also provide lower CO_2 emissions per tonne of cement.

The selection of the appropriate additive largely depends on how the SCM influences cement performance. For example, slag and fly ash have negative influence on early strength and setting time, so that additive formulations are used that can shorten setting time and increase early strength. Limestone cements require an additive that can increase 28-day strength, while some SCMs may require an additive that reduces water demand. Formulated cement additives have been used for more than 80 years and can readily provide strength gains in the range 2–10MPa (both early and at 28 days). Thus it is quite common that cement additives can lower clinker factor (increasing SCM levels) by some 3-10 per cent. The economic benefit arising from lower clinker factor is not discussed here but largely depends on the cost differential between SCM and clinker. Reducing clinker factor does, however, provide a direct reduction in emissions of CO_2/t of cement, by some 26-86kg.

Table 2: the impact of lowering the clinker factor on CO_2 emissions per tonne of cement

Parameter	Value	CO_2 emissions (CO_2 kg/t cement)
Clinker factor (%)	75	647
Power consumption (kWh/t)	45	23
Mill optimisation energy saving (%)	10-15	2.3-3.5
VRM vs ball mill (%)	25	6
Fineness reduction (m²/kg)	10	0.5-1
Strength increase, reduced cement fineness (MPa)	1	1-2
Optimising clinker microstructure on grindability/strength		5-6
Reduced clinker factor in cement (%)	1	8-9
Strength increase, reduced clinker factor (MPa)	1	8-17
QI cement additive – reduced clinker factor (%)	3-10	26-86

Notes: 1. Clinker at 862kg CO_2/t
2. Cement grinding at 45kWh/t
3. 1kWh = 0.5kg CO_2

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The above means of reducing emissions of CO_2/t are summarised in Table 2, highlighting the important scope available from reducing the clinker factor in comparison with that of improving mill efficiency or clinker activity. ■

References

1 Cement Sustainability Initiative www.wbcsdcement.org

2 HENDRIKS, CA, WORREL, E, DE JAGER, D, BLOK, K and RIEMER, P. (2004) 'Emission Reduction of Greenhouse Gases from the Cement Industry' in: *Proceedings of the 7th international conference on greenhouse gas control technologies, IEA GHG R&D Program, Vancouver, Canada.*

3 MOIR, GK (1983) 'Improvements in the early strength properties of Portland cement'. *Phil. Trans. Roy. Soc. London, vA310, p127-138.*

4 IEA Statistics (2012) 'CO_2 Emissions from Fuel Combustion' www.iea.org/co2highlights/co2highlights.pdf

5 O-SEPA (1984) 'A new high performance air classifier' in: *World Cement v15 no.1, p13-24.*

6 HEPHER, NM, and SUMNER, MS (1985) 'Optimisation of Cement Mill Performance' in: *ZKG v38 no.10, p591-592.*

7 MASSAZZA, F and TESTOLIN, M (1980) 'Latest developments in the use of admixtures for cement and concrete' in: *Il Cemento v77, no. 2 p73-146.*

8 SUMNER, M (2010) 'Ensuring Additive Rewards' in: *International Cement Review, no. 9, p71-74.*

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