# The influence of heat curing on durability properties of precast concrete

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**The type and duration of curing has in recent years been an area of considerable discussion among specifiers and suppliers of precast concrete elements. Heat curing is regularly specified in order to speed up early strength development. However, this is sometimes perceived to negatively affect durability properties since heat curing may result in a coarsening of the concrete microstructure. The time to cessation of curing of precast concrete can be assessed using the maturity approach or by comparing the equivalent durability performance. This paper addresses how initial curing temperature and duration affect the microstructure and durability properties of concrete. Findings show that cessation of curing of precast concrete may be possible after 24 hours without negatively affecting the durability potential of the material. Recommendations are made about how the durability of precast concrete can be quality assured by suppliers of these products.**

Assessing the time to cessation of curing of concrete is important for precast concrete as heat treatment and differences between design and production make standard curing guidelines less relevant than for in situ cast concrete [1]. The extrinsic (processing) and intrinsic (material) differences found in precast concrete may allow a reduction in curing duration without compromising strength and durability of the material. This paper considers how the time to cessation of curing may be assessed using either maturity or from equivalent durability.

## Thermal curing and the effects on concrete properties

Thermal curing of concrete promotes rapid hydration of cement that improves early strength but causes hydration products to precipitate near the cement grain surface and reduces further hydration [2]. This affects the pore size distribution within concrete producing more medium and large-sized pores, which has the potential to reduce potential durability of concrete [3]. High initial curing temperatures above 60oC may coarsen the concrete microstructure and hence significantly reduce the intended benefit of early maturity [4].
The maturity approach used to assess the time to cessation of curing is based on strength providing an indication of overall microstructural development [5]. However, maturity calculations cannot predict the microstructural quality controlling durability performance. This is illustrated in Figure 1, where equivalent maturity of precast concrete would require overnight curing of 60°C to match standard wet curing of three days (see also [6]). In reality, precast concrete mixes also differ from design so simple maturity comparisons may be misleading.

A relative maturity methodology is used in some concrete standards such as AS 3600 where cessation of curing is permissible, typically at 80% of grade strength (e.g., 24 MPa for grade 30 MPa concrete) [7]. This paper uses equivalent durability performance to investigate the influence of heat curing on concrete strength and durability properties. The research methodology was based on performance determined from engineering properties that influence structural and durability performance of concrete.

## Experimental investigations

The experimental testing was divided into two parts – testing of high strength concrete, undertaken at the University of Cape Town (UCT) in South Africa, and testing of concrete with moderate to high strength at the University of Canterbury (UC) IN New Zealand. The experiments at UCT aimed at investigating the general influence of curing temperatures on the concrete microstructure. The experiments at UC aimed at directly comparing the performance of typical in-situ versus precast concrete mixes in order to assess the related design requirements.

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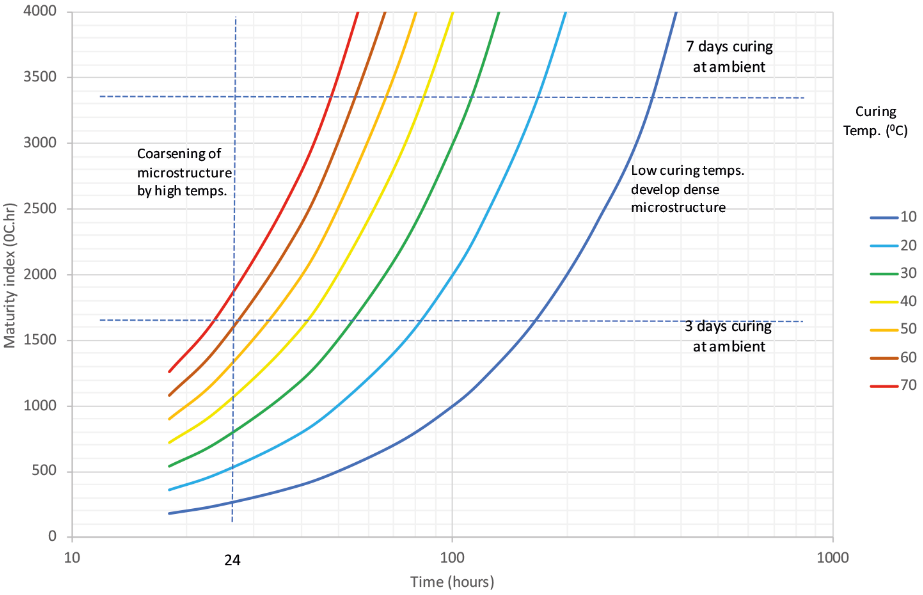

*Fig. 1: Relationship between maturity index and concrete curing temperature (based on [6])*

In both investigations, two different cement types, manufactured in New Zealand, were used: A general purpose CEM I (GP) and a high early strength cement (HE) typical for precast manufacture. Chemical admixtures used were those typically found in concrete production for the grades of concrete investigated.

A part of this experimental investigation was discussed in [8].

## High strength precast concrete mixes

Experimental testing at UCT was undertaken using 2 concrete mix designs using the composition shown in Table 1. The coarse aggregate was a greywacke stone with the sand being a mix of natural dune sand and crushed greywacke (50/50).

Testing of concrete was done for compressive strength development (cubes, 100 mm) while the durability properties were assessed using the South African method for oxygen permeability [9 – 11]. The Oxygen Permeability Index (OPI) test presents a useful and reliable assessment of the concrete pore structure and pore connectivity and is used in South Africa in the performance-based design of concrete structures for exposure classes XC (carbonation-induced corrosion). In particular, the test is very sensitive to the influences of mix composition, compaction and curing conditions on the microstructure of concrete.

The sampled concrete cubes were cured under 5 different curing regimes as listed below. Heat curing was done as follows: seal moulds against water loss and leave them standing for 4 hours after casting, place moulds in an oven at room temperature and increase to the required temperature over a period of 2 hours, expose samples to the curing temperature for 18 hours, followed by demoulding and storing samples at 23°C and 50% RH until reaching the test age of 28 days.

- Ambient curing (23°C, 50% RH)
- Water Curing
- 40°C Heat Curing
- 55°C Heat Curing
- 70°C Heat Curing

*Table 1: Mix design constituent materials, high strength concrete mix*

| **Constituent / property** | **kg/m³** |
|---|---|
| Portland cement (GP or HE) | 381 |
| Water | 160 |
| Sand (50/50 dune / crusher dust) | 801 |
| Stone (19 mm) | 1050 |
| SP SikaViscoCrete -90 HE (ml) | 1524 |
| Acc SikaRapid -2 (ml) | 2960 |
| w/c ratio | 0.42 |

## Mixes with moderate to high strength

The mix compositions used at the University of Canterbury are listed in Table 2. Experimental testing was undertaken using two control and four precast concrete mixes. Control concrete was exposed to ambient initial curing at 21°C before being wet cured for either three or seven days, representing in-situ concrete construction. Similar to what was discussed above, precast concrete cylinders were initially kept at 21°C for four hours; subsequently the temperature increased over two hours before specimens were exposed to either 21, 30, 40 or 50°C for a further 18 hours whereafter cylinders were demoulded and the test face exposed to drying (21°C and 60% RH).

Carbonation and chloride resistance of the cover concrete was assessed at 28 days using oxygen permeability, accelerated carbonation and rapid chloride migration [12 - 14].

Several tests were undertaken for strength and durability assessment with the following testing reported in this paper:

- Compressive strength at 1, 7 & 28 days
- Chloride migration testing was undertaken in accordance with NTB 492 where a 30V potential difference was applied across saturated concrete sampled and the resulting chloride front measured after 24 hours [13]
- Accelerated carbonation testing was done in accordance with ISO 1920 where concrete samples were exposed to 2.5% carbon dioxide for a period of 56 days [14]

*Table 2: Concrete mix designs, precast versus in-situ (kg/m$^3$)*

| **Constituent / property** | **GP30 Control** | **GP35 Control** | **GP40 Precast** | **HE40 Precast** | **GP45 Precast** | **HE45 Precast** |
|---|---|---|---|---|---|---|
| Portland cement | 265 GP | 300 GP | 360 GP | 360 HE | 380 GP | 380 HE |
| Water | 162 | 165 | 165 | 158 | 165 | 158 |
| Fine aggregate | 885 | 875 | 875 | 885 | 860 | 870 |
| Coarse aggregate | 1100 | 1050 | 1050 | 1050 | 1050 | 1050 |
| Water reducer (ml) | 1080 | 1500 | 1800 | 0 | 1900 | 0 |
| Air entrainer (ml) | 100 | 0 | 0 | 0 | 0 | 0 |
| Super-plasticiser (ml) | 0 | 0 | 0 | 1900 | 0 | 2000 |
| w/c ratio | 0.61 | 0.55 | 0.46 | 0.43 | 0.43 | 0.41 |
| fc, 28-days (MPa) | 33.4 | 42.3 | 50.9 | 58.5 | 56.2 | 72.6 |

## Experimental results

### The influence of heat curing on compressive strength development

The influence of heat curing on compressive strength development is illustrated in Figures 2 and 3 (including error bars for standard deviation) using the results obtained at UCT. As expected, heat curing results in initially higher strength values especially at an early age, with one-day strength values being significantly higher compared to concrete cured in water or under ambient conditions. At 28 days of age, the strength of heat-cured samples was still higher than that compared of samples cured under ambient conditions, especially for the general-purpose cement (GP). Overall, in this study, no significant negative effect of heat curing on later-age compressive strength was observed.

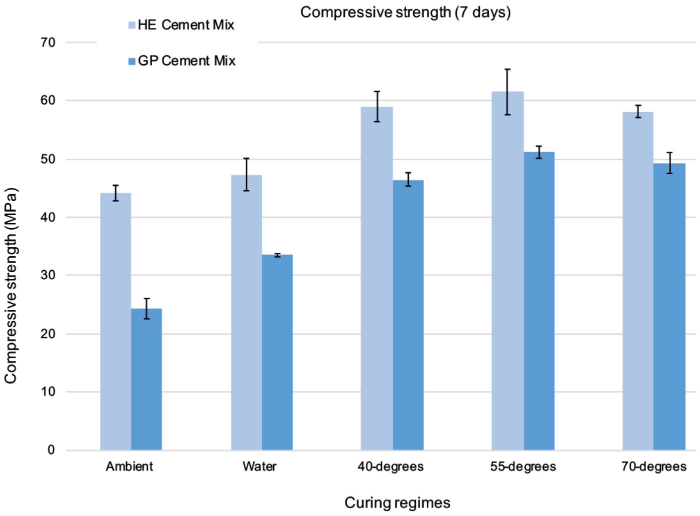

Fig. 2: Influence of initial curing temperature on 1-day compressive strength

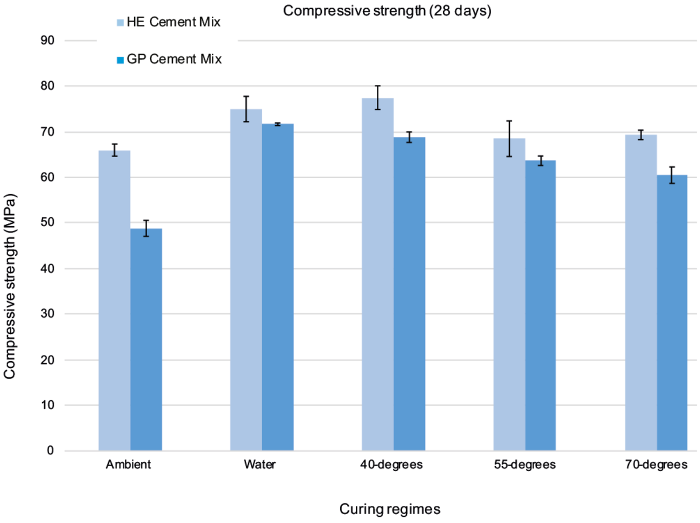

Fig. 3: Influence of initial curing temperature on 28-day compressive strength

### Coefficient of permeability

The test results for oxygen permeability are presented in Figure 4. A lower value indicates a concrete of higher durability. The test results indicate that heat curing has had no negative effect on the durability properties of the tested mix compositions, independent of the cement type. For all curing temperatures, durability properties were equal to those measured on fully water-cured samples and significantly better compared to concrete cured under simulated ambient conditions.

### Chloride resistance

Testing the chloride resistance of grade 30 and 35 MPa concrete (UC experimental programme) showed relatively poor performance even after standard curing of three or seven days (Fig. 5). Chloride migration coefficients determined from rapid chloride migration testing were above 18x$10^{-12}$ m²/s whereas precast concrete had moderate to good chloride resistance with diffusion coefficients between 6-15x$10^{-12}$ m²/s. Optimum initial curing temperature was around 40°C with higher diffusion coefficients measured when the curing temperature was increased to 50°C. This effect of heating has been found by some researchers but not by others [15,16]. Concrete that contains HE cement had lower migration coefficients than similar concrete made with GP cement.

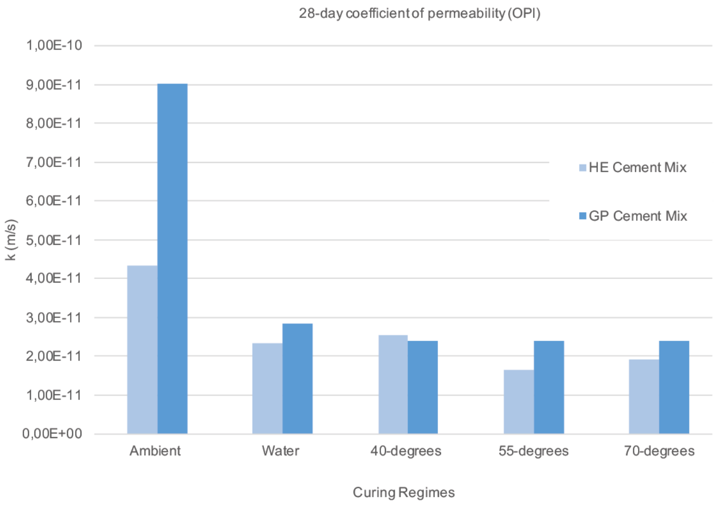

*Fig. 4: Influence of initial curing temperature on the coefficient of permeability*

### Accelerated carbonation

Accelerated carbonation was measured in accordance with ISO 1920 where concrete test samples were exposed to 2.5% carbon dioxide at an age of 28 days. Depth of carbonation was determined after 56 days exposure in the carbonation chamber, with results shown in Figure 6. Results showed that precast concrete without any active wet curing had similar or lower carbonation depth compared with control concrete. Carbonation depths were also found to reduce with increased maturity induced by heating of precast concrete (e.g. higher initial curing temperatures were found to produce better carbonation resistance).

## Discussion

Simple maturity estimations for the cessation of curing do not make specific allowance for microstructural changes that occur at high temperatures and are more appropriate when dealing with moderate temperatures below 50°C. Using strength as a surrogate measure of durability may also be misleading especially when dealing with some binder systems with slower reactivity (e.g., fly ash concrete). This can be seen in Figure 7 where the strength at cessation of curing is compared with diffusion coefficients from the rapid chloride migration test. Whilst the precast concrete mixes exposed to only 24 hours curing showed a reasonable relationship with maturity (e.g., moderate to good chloride resistance when strength is more than 24 MPa), control concretes in some cases had strengths above 24 MPa but were still found to have poor chloride resistance.

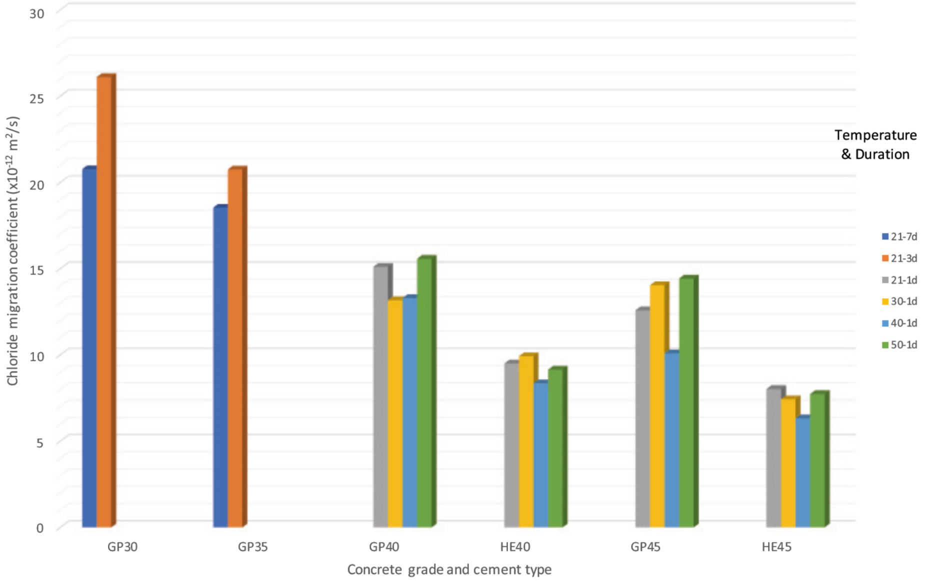

*Fig. 5: Chloride migration coefficients measured at 28 days*

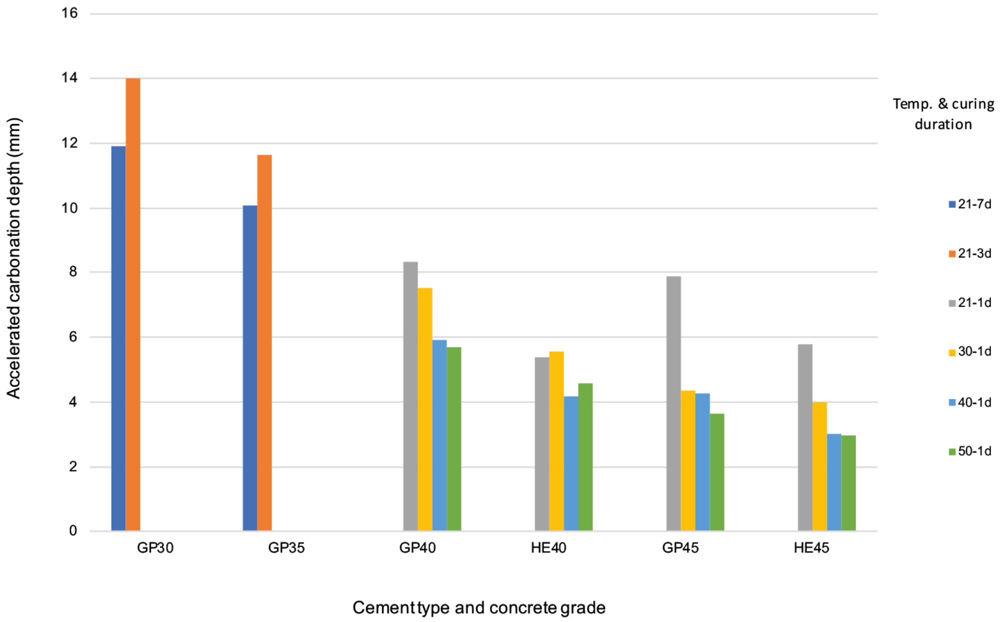

*Fig. 6: Accelerated carbonation depths measured after 56 days exposure*

Similarly, for carbonation, using the maturity index approach does not provide a reliable basis for ensuring that control concrete achieves high resistance to carbonation, especially in cases where only moderate strength is specified such as 30 MPa. This is shown in Figure 8 where lower strength control concrete had consistently higher carbonation depths when tested in accordance with ISO 1920.

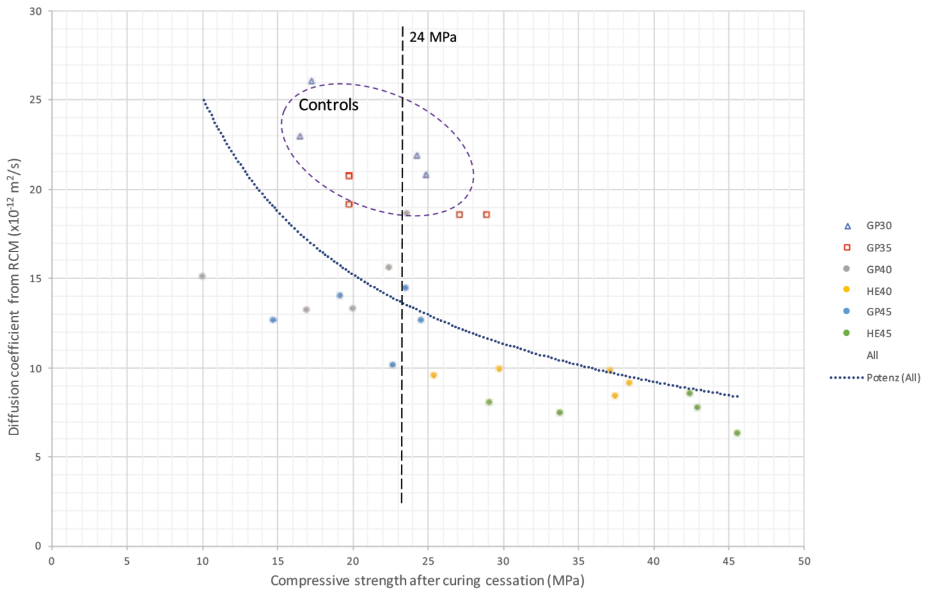

Fig. 7: Strength at cessation of curing versus diffusion coefficient at 28 days

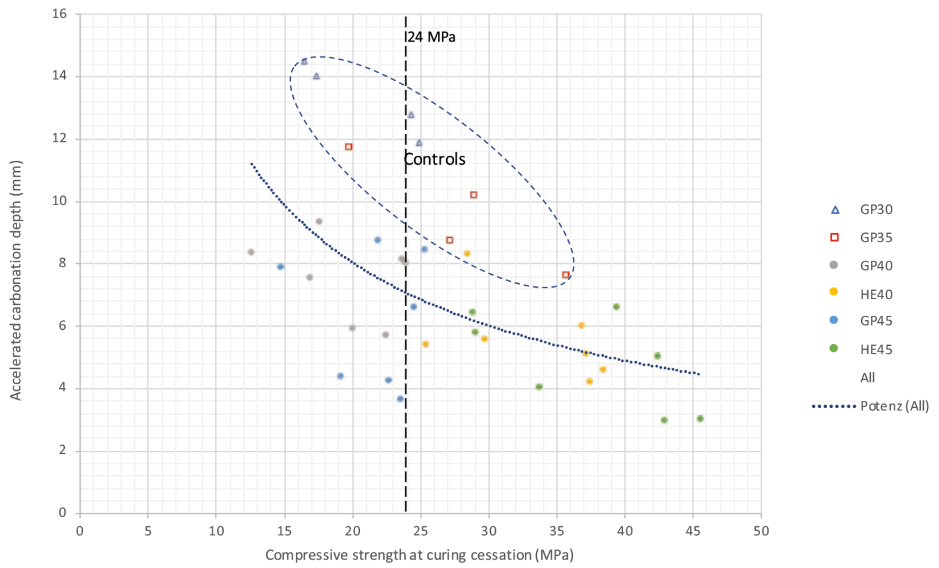

Fig. 8: Strength at cessation of curing versus accelerated carbonation depth

## Recommendations

When precast concrete suppliers substitute higher grade concrete than required for design, this not only allows early handling but also produces higher durability potential of the material. This improvement in the quality of the microstructure of concrete is apparent even when initial curing does not include active moist curing.

Precast concrete producers should provide a rigorous methodology to provide assurance about the expected durability of the elements. A practical way to do this is to use performance-based test methods related to durability indicators.

Experience with supply of precast concrete suggests that units are often made using concrete that are two grades higher than specified (e.g., grade 40 MPa for 30 MPa or 45 MPa for 35 MPa). This research has shown that this approach can provide adequate durability even when precast concrete has no active moist curing.

In general, design engineers should consider the higher strength and superior durability of precast elements, compared to in-situ concrete, in their structural and conceptual design.

## Conclusions

Findings from this testing programme showed that estimating the cessation of curing needs to consider more than maturity effects when dealing with moderate concrete strengths. This was seen when comparing the performance of HE cement compared with GP cement and also when analyzing microstructural changes that occur at high curing temperatures. Simple maturity calculations may become unreliable at high curing temperatures, typically above 50-60°C, and when dealing with different concrete types.
The quality of cover concrete may be influenced by the temperature and duration of thermal curing applied to precast

concrete during production. This effect can be controlled and evaluated with implementation of a suitable experimental quality control programme based on the measurement of simple durability indicators.

## Acknowledgements

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