INVESTIGATING TEMPERATURE MATCHED CURING FOR NEW ZEALAND CONDITIONS

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SUMMARY

Temperature Matched Curing (TMC) is a technique that involves matching the temperature of curing cylinders with the temperature of the in-situ concrete, to provide a superior measure of early age concrete strength. The technique has been used in this study to investigate the early age strength formation of both shallow and deep concrete slabs, and has considered two types of cement and two cement dosages. A particular feature is the use of cellular telecommunications technology so that the curing samples need not be in close proximity to the project, referred to as Remote Temperature Matched Curing (RTMC). The paper presents the historical development and background to TMC and a description of the equipment used to conduct the curing.

INTRODUCTION

Increase in the use of post-tensioned concrete slabs, particularly for ground flooring, has emphasised the need to accurately predict the early (pre 7-day) compression strength of concrete slabs as knowledge of concrete compression strength is essential when timing the stressing operation. Early compressive strength is typically established using test cylinders cast in accordance with NZS 3112:Part 2. Test cylinders are left undisturbed in their moulds for no less than 16 hours before being removed from their moulds and cured completely submerged in water at a constant temperature of 21°C ± 2°C. Often during that initial 16-24 hours the moulds are not maintained at the 21°C temperature, but are left sitting in laboratories.

An alternative to laboratory curing, and also described in NZS 3112:Part 2, involves curing the cylinders on site at ambient temperatures through wrapping cylinders in impermeable plastic and placing them as close to the relevant concrete as possible. This method allows moisture content to remain relatively high while hopefully better representing the in-situ temperatures.

Though generally impractical, another alternative method is to test concrete cores to determine in-situ strength. However, it is generally recognised that the strength results of concrete cores taken at 7 days are negatively influenced by the coring process, by the presence of any reinforcement, and by the fact that at least some of the aggregates in a drilled core are only partially bonded to the cement matrix.

It is well documented that lab cured and site cured cylinders significantly underestimate early age compressive strength because they do not allow for the high internal temperatures that occur during curing of large slabs. These high internal temperatures cause accelerated strength gain. Consequently more accurate methods for determining and improving upon the accuracy of early compression strength prediction have been explored.

Maturity testing is a cheap and relatively simple non-destructive method for the strength prediction of in-situ concrete. The method utilises internal temperature and concrete age to estimate strength and must be calibrated and tested for each specific mix design [1]. Any significant differences between mixing and curing of the initial calibration sample and the in-situ concrete can lead to discrepancies between the predicted and actual compression strength. This, combined with different mix designs for different plants and different projects (and hence continued need for calibration of maturity meters), has lead to the disuse of maturity testing in the New Zealand concrete industry.

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Temperature Matched Curing (TMC) is a proven method for increasing the accuracy of compressive strength prediction for concrete structural elements. It involves matching the temperature at which the test cylinders are cured with the internal temperature of the concrete slab under investigation. Although a great deal of research has been undertaken into TMC globally, little effort has previously been made to specifically confirm the suitability of this technology for New Zealand conditions and for the types of cements used in New Zealand. For instance, the cements manufactured by both Golden Bay Cement and by Holcim (New Zealand) Ltd tend to be more finely ground than the international norm, which produces early hydration, greater heat of hydration and thus higher early age strengths.

THE HISTORY OF TEMPERATURE MATCHED CURING

Temperature matched curing has been used in laboratory conditions from as early as 1931 when Davey carried out studies in Britain examining the effects of cement type, cement content and the effect of placing temperature on the strength development of TMC specimens compared to those cured at 17°C [2]. At about the same time Davis and Troxell carried out similar laboratory studies in the U.S.A [2]. In 1970 the first patent of a TMC system was taken out by Maurice Thompson [2]. The 1970’s also saw introduction of the first in-situ application of TMC when it was used by Blakey of John Laing Research for the removal of formwork on a concrete framed building [3], and then by Bamforth of Taylor Woodrow construction to examine the properties of concrete at the centre of a large pour [4].

In 1983 Harrison from the CCA (Britain) made comparative studies between cubes cured on site and cubes cured utilising TMC technology, clearly demonstrating that cubes cured on site, provided conservative estimates of in-situ strength [5]. In the same article Harrison stated that “the main uses of TMC are as extremely effective methods of assessing formwork striking or prestressing times.” A separate 1983 laboratory study by Tollocsko and Wainwright introduced a microcomputer to combine the temperature monitoring, tank control and data logging processes involved in TMC [6]. In 1984 the British Standards Institution issued a draft development No. 92, “Method of temperature-matched curing of concrete specimens” which was adopted into BS 1881: Methods for testing concrete [7].

In 1986 Cannon reported a field study of actual projects that involved different cement types and blends. The study also considered different structural element sizes, with least dimension ranging from 125 mm to 4.5 m, considered different cement contents and involved the deployment of TMC thermocouples placed at both the face and the centre of elements [8]. As would be anticipated, Cannon found that in all cases the early strength development as given by on site cylinders gave the lowest results, followed by 20°C curing, with TMC measured at the face exceeding this value by up to 3 times after 24 hours, and TMC measured at the centre giving even higher strengths. Cannon also reported that TMC can meet specifications to be successfully used to the benefit of both contractor and client [8].

More recently TMC technology has been utilised for a variety of lab trials, often involving different concrete types, and for the testing of properties other than compressive strength. Particularly noteworthy are the studies carried out by Khan, Cook and Mitchell reported in 1995 and 1996 in the ACI Materials Journal. Their study on the tensile strength of different strength concretes demonstrated that the modulus of rupture for TMC beams was higher than that of sealed air-dried beams [9], while their study on early age compressive stress-strain properties demonstrated that the early age compressive strength of cylinders cured using TMC was higher than that of both cylinders protected against moisture loss and of air dried cylinders [10]. This increased concrete strength was believed to be directly attributable to the effect of elevated temperature.

Also of particular note was a study carried out by W.F Price and J.P Hynes [11] of Taywood Engineering Ltd. They undertook a study comparing different methods for the estimation of in-situ compressive strength for high strength concrete’s [11]. The methods tested were temperature matched curing using an oven (rather than a waterbath as in the current study), ultrasonic pulse velocity measurement, pull-out testing and maturity-strength relationships [11]. Additional test cubes were water cured in the standard way, and also sealed in polythene sheeting and cured at a constant 20°C. Furthermore, cores were drilled at 7, 28 and 90 days. It was concluded that the TMC samples (if sealed against contact with water during the curing period) most closely matched the in-situ strength as measured by drilled core samples [11].
EXPERIMENTAL STUDY

Objectives

This study focused on two objectives:

- The primary objective was to assess the accuracy with which traditionally cured test cylinders (21°C ± 2°C), test cylinders wrapped in plastic and cured alongside in-situ concrete, and temperature match cured cylinders representing the in-situ strength of mass concrete.

- The secondary objective was to determine the effects of slab thickness and ambient temperature on the internal temperature of mass concrete, and the subsequent effect this has on early compressive strength.

The Remote Temperature Matched Curing Device

As shown in Figure 1, the Remote Temperature Matched Curing device (RTMC) is comprised of two units, a remote unit which gathers temperature data on site (see Figure 2) and a base unit which is connected to a waterbath and can be placed in any convenient location (see Figure 3). The remote unit utilises thermocouples to monitor and record the temperature of the mass concrete on site, where a thermocouple is a temperature sensor consisting of a pair of dissimilar metals. The electrical potential difference created at the junction of these two wires is measured and related to temperature change, allowing temperature data to be gathered. This data is then transferred to the base unit via a cellular transmission and the attached waterbath temperature adjusted to match accordingly. All temperature data, including waterbath temperature, is stored in the base unit and then emailed to a nominated address, allowing for a direct comparison of the temperature curve of
the concrete and of the bath over the entire curing period. This allows determination of the accuracy with which the temperatures of the in-situ concrete and the waterbath have been “matched”. In many situations this can be used to highlight the temperature differential between the internal and external concrete to avoid thermal cracking.

**Concrete Composition and Materials**

This study examined three concrete mix designs, employing both Holcim and Golden Bay GP cements at contents of 350 kg/m³, and Golden Bay GP cement at 275 kg/m³. In all mixes a combination of Auckland Basalt and Silica Sand was used as aggregate, and to ensure the mixes were representative of the industry standard a water reducer at dosages of 300 ml per cubic metre was incorporated into the mix design. The 275 kg/m³ mix also contained an air-entraining agent with a dosage of 65 ml per cubic metre of concrete. The free moisture content of the aggregates was measured prior to batching, and the mix design adjusted accordingly. All concrete was mixed in trucks, with batch sizes of 1.5 m³. The target 28 day compressive strengths for these mixes was 25 MPa and 40 MPa respectively. The detailed mix designs are given in Table 1.

**Production of Test Slabs and trial programme**

Eight trial slabs having plan dimensions of 700 by 700 mm were cast in order to determine the in-situ early compressive strength in concrete floor slabs. Plywood boxing with polystyrene insulated sides was used so that the trial slabs could be considered representative of larger mass concrete slabs. The plywood base sat on 100 x 50 mm framing to which the sides were screwed.

For each mix design a 150 mm deep slab and 700 mm deep slab was cast, using a skip and an air driven vibrating poker for compaction. The exposed top of the slab was then covered in polythene sheeting to entrap moisture.

Prior to casting each slab a D10 reinforcing bar (length equal to the depth of the slab) was placed upright in the centre of the boxing to hold thermocouples.

Thermocouples were then attached at depths of 20 mm from the surface of each slab, and at the centre of each slab. For the 150 mm deep slab an additional thermocouple was inserted at a depth of 130 mm. For the 700 mm deep slab additional thermocouples were inserted 150 mm and 550 mm from the surface.

Four trials were carried out using test slabs. The first three trials were carried out on mixes 1, 2 and 3, for which the thermocouple in the centre of the 700 mm deep slab controlled the TMC system. For the fourth trial the TMC was controlled by the thermocouple at the centre of the 150 mm deep slab. The other thermocouples allowed the internal temperature profile of the slabs to be mapped, and maturity measurements to be made.

Concurrent to the casting of test slabs for each trial, 43 test cylinders were produced. Of these, 14 cylinders were sealed in their moulds and immediately placed into the TMC water bath. The remaining cylinders were left in their moulds for 24 hours, after which 14 were placed into a standard water bath (21°C±2°C), and 15 wrapped in polyethylene sheets and placed next to the test slabs. The cylinders

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Table 1. Mix Design Properties

<table>
<thead>
<tr>
<th></th>
<th>Mix 1 (350 kg/m³)</th>
<th>Mix 2 (275 kg/m³)</th>
<th>Mix 3 (350 kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cement Type</strong></td>
<td>Holcim GP</td>
<td>Golden Bay GP</td>
<td>Golden Bay GP</td>
</tr>
<tr>
<td><strong>Target Strength (MPa)</strong></td>
<td>40</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td><strong>GP Cement (kg/m³)</strong></td>
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<td>275</td>
<td>350</td>
</tr>
<tr>
<td><strong>20mm Basalt (kg/m³)</strong></td>
<td>700</td>
<td>600</td>
<td>700</td>
</tr>
<tr>
<td><strong>13mm Basalt (kg/m³)</strong></td>
<td>375</td>
<td>440</td>
<td>375</td>
</tr>
<tr>
<td><strong>7mm Basalt Pap (kg/m³)</strong></td>
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<td>615</td>
<td>600</td>
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<tr>
<td><strong>Silica Sand (kg/m³)</strong></td>
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<td>315</td>
<td>360</td>
</tr>
<tr>
<td><strong>Total Free Water (kg/m³)</strong></td>
<td>170</td>
<td>167</td>
<td>170</td>
</tr>
<tr>
<td><strong>Water Reducer (ml)</strong></td>
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<td>825</td>
<td>1050</td>
</tr>
<tr>
<td><strong>Air Entraining Agent (ml)</strong></td>
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<td>65</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Estimated Initial Slump (mm)</strong></td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>
initially placed in the TMC water bath were struck from their moulds and returned to the TMC bath after 24 hours. Cylinders cured using each method were tested 1, 2, 3, 4, 5, 7 and 28 days after casting. A thermocouple was inserted into one of the cylinders cured next to the test slabs.

Core samples with diameters of approximately 100 mm were drilled from each test slab at 7 and 28 days after casting, allowing for a direct measure of in-situ strength at these ages. The cores were all trimmed to a length/diameter ratio of approximately 2, and the ends capped in accordance with NZS 3112:Part 2. The cores were tested on the same day that they were removed from the slabs. As mentioned earlier the TMC results were taken as the best representation of the early age strength of the in-situ concrete.

The ambient temperature and humidity around the test slabs was measured using a digital device. All temperature measurements were taken at 15-minute intervals.

**DISCUSSION OF RESULTS**

Results and discussion will be presented in September.

**REFERENCES**

7. BS 1881: *Testing of Concrete -Part 130: Method for temperature matched curing of concrete specimens.*