Temperature Matched Curing Systems

by A. Williams

Synopsis: Early age concrete is subject to a temperature rise due to the hydration of the cement. Cube or cylinder reference specimens stored alongside a structure will not exhibit this temperature rise to the same degree and therefore will not have the same maturity as the concrete in the structure. Temperature matched curing is a method whereby cubes or cylinders of a similar maturity to the structure are produced, and is an extremely efficient method of determining minimum formwork striking and prestressing time.

This paper gives a brief account of the history behind temperature matched curing in the United Kingdom, where the recent issue of a British Standard Institution document has focussed attention to the subject.

Details are presented of the design and construction of a portable matching system for use on site. The system which is extremely robust, (but light enough to be carried by one man), is able to control cube temperatures to within ± 1°C of the concrete temperature within a structure.

Results are given which show the advantages and disadvantages of such a system and illustrate the difference of maturity and hence strength between reference cubes stored in the curing bath and reference cubes placed next to the structure itself.

Keywords: age-strength relation; concretes; curing; hydration; portland cements; temperature; tests.

A Williams has worked on problems associated with the design and construction of concrete structures for a period of 20 years. For fourteen of those years he has been engaged on research at the Cement & Concrete Association, United Kingdom, where he has published a number of reports on a variety of subjects. At the present time, he is a member of a group specialising in the development and promotion of equipment, materials and processes for use in the concrete and associated industries.

INTRODUCTION

An estimation of the strength of concrete in a structure is obtained by testing reference specimens cast at the same time as the structure. The strength of concrete is a function of the materials used and their mix proportions, also its moisture state and maturity. It is unlikely that reference cubes or cylinders will have the same strength as the *in-situ* concrete due to variations in mix proportions, compaction and moisture level. However for mature concrete, an allowance for these differences can be made, and this is taken into account in the partial factor for safety for concrete in design codes. For early age concrete, gross differences in maturity can occur between the reference specimens and the *in-situ* concrete. This difference is minimised by producing test cubes of equal maturity to the structure.

Temperature matched cubes, where the reference cubes follow the same temperature as the parent concrete have the same maturity as the parent concrete, and therefore give a more realistic estimation of the strength of the structure.

The object of this paper is to describe the basic elements of a temperature matched curing system, to briefly relate the history of temperature matched curing in the United Kingdom, and finally to give details of typical results obtained on site using a portable temperature matching system.

BACKGROUND INFORMATION

The hydraulic reaction that takes place when cement hydrates is exothermic in nature and usually causes the temperature of the *in-situ* concrete to rise considerably. The larger the mass of concrete, the greater will be the rise in temperature, with a consequent increase in the rate of strength development. Reference test cubes or cylinders stored alongside the structure will also exhibit a rise in temperature. Because of the much lower mass of concrete involved, and the proximity of the steel sides of the mold, the temperature rise exhibited by the reference specimens will be much less than that of the parent concrete. Because of the difference in maturity, the test specimens will underestimate the strength developed by the *in-situ* concrete by as much as 50% during the early age of the structure. Temperature matching is a method whereby cubes of the same maturity as the structure are actually produced, this is an obvious advantage over using the maturity method, as no assumptions or calculations have to be carried out.

The basic elements of a matched curing system are shown in Figure 1 and consist of:

a) curing bath fitted with a water circulator and heater;

b) two temperature measuring devices, one placed in the curing bath and a second used to measure the temperature of the *in-situ* concrete;

c) a control box which monitors the output from the temperature sensors and switches on the heater as required.

In temperature matched curing, the reference test molds are filled and compacted in the normal manner, but the top open surface is covered by a flat steel or glass plate prior to placing the mold in the water bath. The function of the cover plate is to prevent the concrete from being washed out of the mold by the water circulating in the tank, but it does not form a complete seal. The intention is to allow sufficient water to reach the cube, to give wet curing conditions. Alternatively, by using a steel plate with a rubber seal, the water can be prevented from reaching the concrete if required.

The basic ideas behind temperature matching have been known for a considerable time. Davey (1) published a paper in 1933 which describes in detail an adiabatic curing system (Figure 2), in which the reference specimens were constrained to follow the temperature of an enclosed volume of concrete. In that particular case, the control sample was placed in an insulated flask, which itself was placed in the curing tank. By subjecting this control sample to adiabatic curing conditions, it served to represent the centre of a mass concrete structure.

Since that time, a number of papers have been presented on temperature matched curing (2, 3 and 4) two of these relate to laboratory facilities which are much too large or complex to be used on a construction site. The paper by Blakey (2) described a portable system for use on site. A number of systems based on this design were manufactured and used, but operational problems with the equipment eventually led to them being withdrawn from general use, although several still exist.

In the United Kingdom, interest in temperature matched curing has been stimulated recently by the issuing of a British Standard Draft for Development (DD 92:1984) (5) which covers the subject, and details the specific requirements of a temperature matching system. The portable unit shown in Figure 3 was designed to meet this specification, for use on site. The system consists of a microprocessor based temperature controller mounted in a portable steel cabinet. Temperatures are measured by platinum resistance thermometers housed in stainless steel probes, one positioned in the bath and the other, an insertion probe (Figure 4) in the *in-situ* concrete. This probe is recoverable after the concrete has set. The controller is capable of maintaining the bath temperature to within ± 1°C of the temperature measured in the *in-situ* concrete. The temperature probes are connected to the control unit by armoured cables, enabling the unit to be sited at a place of safety at a distance of up to 50 metres from the measuring point. A chart recorder is also fitted in the unit and records the ambient temperature as well as the bath and temperatures. The size of the tank was designed to easily accommodate ten 100 mm cube molds.

SITE RESULTS

One of the arguments in favour of using temperature matched curing is that it is an extremely efficient method of determining minimum formwork striking times. Possibly the main problem associated with temperature matching is that of ensuring the probe measures a representative temperature. A guide to the positioning of the sensor is given in Reference 5.

The following examples illustrate how temperature matched curing systems have been used on different structures.

1. 300mm Wide Wall

As can be seen from Figure 5, a 300 mm wide concrete wall cast in insulated steel formwork showed an increase in temperature of around 17°C some 23 hours after casting. Cubes cured alongside the walls followed the changes in ambient temperature. The difference in strength between these cubes and a second set which were placed in a matched curing tank is readily apparent (Table Figure 5). After some 24 hours, the matched cubes are approximately twice as strong as the 'normal' cubes, and the 3 MPa strength difference is still apparent after 67 hours.

2. 1 Metre Wide Wall

The heavily reinforced blast wall shown in Figure 6 was cast in 10 m long by 3 m high sections (half height sections) in insulated timber-faced forms. For these sections the rise in temperature due to hydration at the centre of the pour was required to be measured, so a thermocouple positioned at the centre was connected to the chart recorder in place of the ambient temperature probe normally used. The difference in temperature between the thermocouple and the probe which was inserted 50 mm into the concrete through one of the side forms would give an indication of the temperature distribution in the wall. The centre of the wall was found to reach a temperature of around 36°C some 27 hours after casting, as compared with a temperature of 27°C near the outer surface (Figure 6).

3. Segmental Box Bridge

For other structures however the position of the insertion probe can be more critical. Figure 7 shows one of the diaphragm units for a glued segmental concrete box bridge which forms part of a single-carriageway road system. The bridge has 8 spans with a maximum span length of 90 m, and grade 52.5 concrete is specified for the precast segments. As the factory is required to produce one segment per day, the soffit forms on the side cantilevers have to be stripped 14 hours after casting, at which time a cube strength of 10 MPa is required. Cubes cast and stored on top of the side cantilevers underneath a thermal insulating blanket reached a strength of 1 MPa at 14 hours despite the fact that warmed water was used when the concrete was mixed. It was anticipated that a concrete temperature of 35°C was required throughout the unit to achieve the specified strength of 10 MPa.

In order to determine typical concrete temperatures, thermocouples were used when the next segment was cast to monitor the temperatures at points in the unit. The concrete temperatures measured in that segment are shown in Figure 8 and it can be seen that whereas the sides and bottom of the box reached temperatures around 35°C, the more exposed cantilevers only reached a temperature some 10°C lower than that value. In this case cubes stored under the thermal blanket had zero strength at 14 hours. Cubes placed in the temperature matched curing bath with the probe positioned in one of the side cantilevers reached a strength of 3.5 MPa.

To carry out a site investigation where the temperature variation throughout the structure is unknown, it is possible to cast 50 mm long stainless steel tubes (closed at the inner end), into the concrete at points where the temperature measurement is required. The ambient temperature measuring probe can be moved from pocket to pocket, allowing a stabilising time of a few minutes in each position. In this way the position in the structure which is giving the lowest temperature increase as recorded on the chart recorder can be determined, and the probe then left in that position.

LABORATORY USAGE

In addition to site testing, temperature matched curing is obviously of use in the laboratory. The use of admixtures and cement replacement materials often change the peak temperature attained due to hydration, also the strength of the concrete. Peak hydrating temperatures which are in excess of 65°C might significantly adversely affect the properties of the concrete.

Typical results from laboratory tests in which the portable matching system was used as shown in Figure 9. For these tests, control specimens were cast in cylindrical plastic moulds encased in very thick thermal insulation. The object was to produce adiabatic curing conditions in a manner similar to that described by Davey (1). The temperatures measured in the control specimens are shown in the figure, as are the compressive strengths obtained from the reference specimens.

CONCLUSION

Temperature matched curing is a method which can readily be used on site for producing cubes or cylinders which are more representative of the strength of the structure. It must be emphasised that the method does not reproduce *in-situ* conditions, but by exactly matching the temperature changes, it does eliminate one of the main reasons for the difference in properties between reference specimens and site concrete.

REFERENCES

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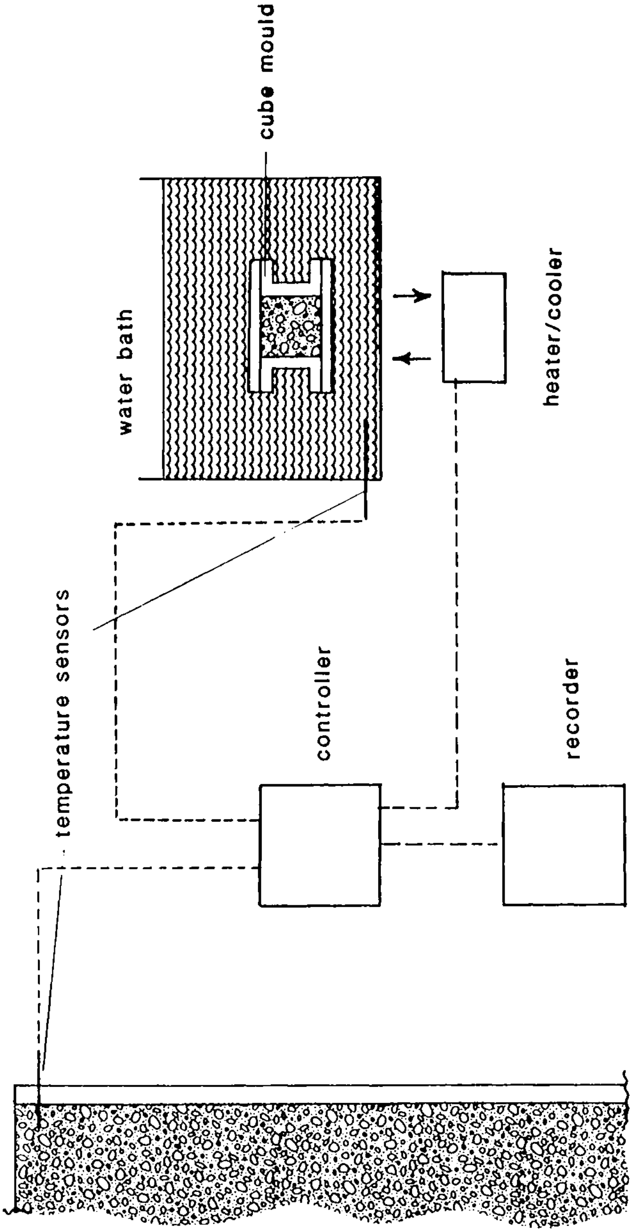

Fig. 1--Temperature matched curing system

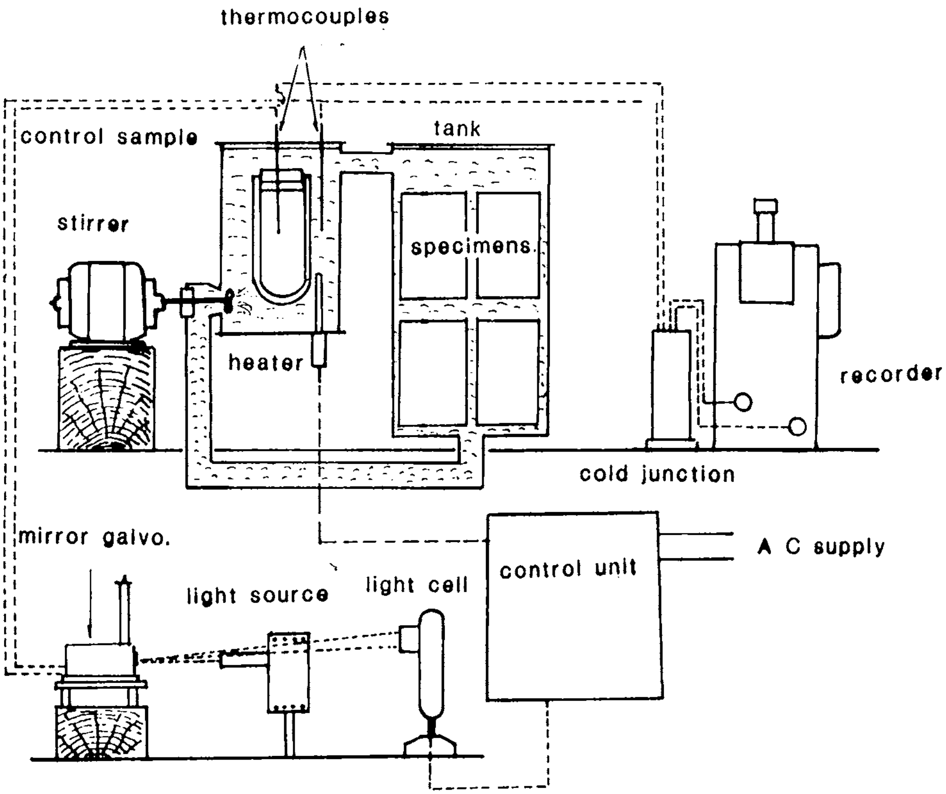

Fig. 2--Davey system circa 1933

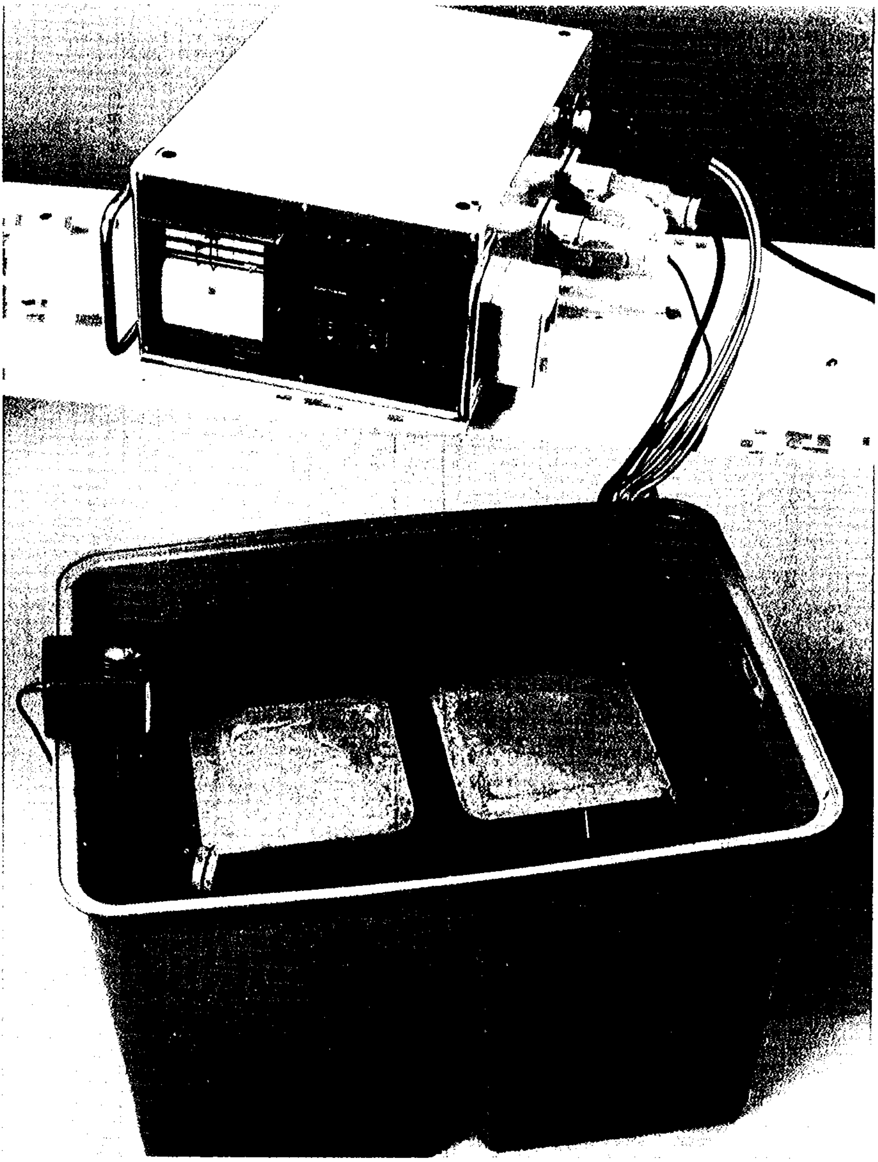

Fig. 3--Portable temperature-matching system

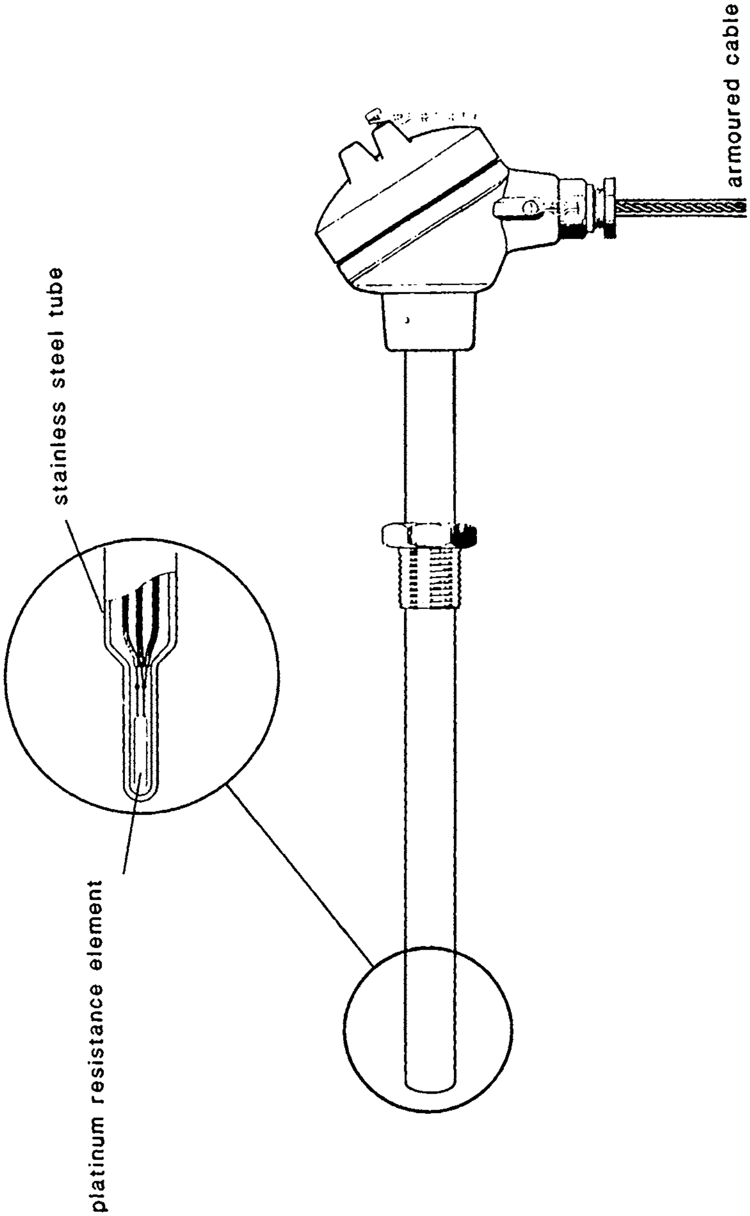

Fig. 4—Insertion probe