UPGRADED TEMPERATURE MATCHED CURING SYSTEM

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ABSTRACT

A computer controlled temperature matched curing system to simulate curing of concrete in structures is presented

The system has capability to accurately control ambient temperature against hydration temperature generated by a fully insulated concrete specimens. Also it is capable of simulating any cooling rate which might occur on site and which depends on thickness of concrete element, type of formwork, ambient temperature, humidity and wind velocity.

Data of concrete of different compositions used at 20 °C and 5 °C and 35 °C are compared with data of concrete cured using semiadiabatic conditions and effect of simulating cooling-time curve is discussed on light of results of strength porosity and permeability.

The influence of fly ash on properties of concrete cured at the different environments is also highlighted.

الملخص

في هذه الدراسة قدم نظام محاكاة بوساطة الحاسوب لعمل نظام تحكم معالجة حراري لتمثيل نظام المعالجة في المنشآت الخرسانية.

للنظام القدرة على التحكم بالحرارة المحيطة والحرارة الناتجة من الإماهة لعينة معزولة تماماً من الخرسانة، كما يمكن تمثيل أي معدل تبريد يمكن أن يحدث في الموقع والذي يعتمد على سماكة العنصر الخرساني، نوع قوالب الصب، الحرارة المحيطة ، الرطوبة وسرعة الرياح.

استخدمت بيانات لخرسانة مصنعة من الأسمنت البورتلاندي العادي ولخرسانة مضاف اليها خبث الأفران بمكونات مختلفة ومعالجة عند 5 °C ، 20 °C ، 35 °C. تمت مقارنة النتائج مع بيانات خرسانة باستخدام المعالجة بالأحوال الأدياباتية وتم مناقشة أثر تمثيل منحنى زمن التبريد على ضوء مناقشة نتائج المقاومة ونسبة الفراغات والنفاذية.

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INTRODUCTION

Because physical, chemical and biological phenomena usually give rise to thermal effects and such effects, if carefully measured provide quantitative description of the phenomena sophisticated measurement systems are available in most branches of science. These systems measure either heat or rate of heat evolution or both.

These measurement systems have been slowly applied to monitor more fully early age behaviour of concrete(1) either by monitoring the temperature fluctuation with time of an insitu concrete structure or/and by subjecting concrete specimens with the same mix properties to an adiabatic curing condition in the laboratory [1,2,3]. The temperature rise due to the hydration reaction is a function of balance between heat generated during this chemical reaction and the heat loss from the concrete, and it depends on the type of cement, nature of mineral aggregates, mix proportion, ambient and placing temperature, structure size shape and the type of formwork and insulation.

For the usual range of Ordinary Portland Cement (OPC) Bogue [4] observed that 50% of total heat is liberated between 1 to 3 days after mixing with water. 75% in 7 days and 85 to 90 % of total heat in 6 months. Davey and Fox[5] detailed a technique for measuring adiabatic temperature rise of concrete. Blakey[6] presented a method of matching insitu temperature behaviour of concrete in samples of that concrete, thereby introducing temperature matched curing technique. The temperature rise data for different section thicknesses and different types of formwork were presented by Harrison[7]. The recorded placing temperature at a number of sites in the UK shows that on average, the placing temperature is 5°C above the main daily temperature. Wainwright and Tolloczk [2] and Harrison[8] sought to demonstrate technique and benefit of data obtained from the process in forecasting actual gain in strength of concrete insitu.

Adiabatic calorimeter have been developed by many researchers [2,9-12], but they differ from each other in terms of sample shape and size, degree of insulation and method of heat supply. The system used in this investigation is upgraded modified version of the system developed by Wainwright and Tolloczko [2,3] The new system provides to allow for better temperature monitoring, control and data acquisition. Also it includes facility of controlling cooling rate of concrete specimens.

ADIABATIC CURING

Concrete is a poor conductor of heat, so initially, the rate of heat generation due to exothermic reaction between water and cement within a concrete section is greater than rate of heat loss from concrete. This results in a net increase of internal temperature. However, as hydration progresses, rate of heat generation decreases and falls below heat loss rate. Then the concrete section begins to cool and to contract. The internal temperature cycle of a concrete section is therefore dependent on two factors, heat generating capacity and heat loss characteristics of the concrete and its surrounding environment.

Heat generation is measured using principle of a calorimeter. This is essentially a reaction vessel surrounded by an environmental container. Calorimeters are divided broadly into those where heat loss to environmental chamber is minimised and those where the reaction vessel is maintained at a controlled temperature. The first class is referred to as adiabatic. If controlled temperature is constant, the second class is designed isothermal. Conduction calorimeters fall into the latter class. Some calorimeters operate to maintain the reaction vessel at a programmed or exterior controlled time temperature profile. The temperature matched curing apparatus which is designed to maintain the environmental temperature of concrete test cubes at temperature of a concrete structure is an example of such calorimeters(13).

The system described in the following section follows the principle of the calorimeter defined as adiabatic

UPGRADED TEMPERATURE MATCHED CURING SYSTEM

CURING TANKS

The general layout of the cyring tank system is shown in Figure 1. This is essentially the same arrangements described in reference (2). Three tanks are interconnected by a network of insulated copper pipes which allows the continuos closed-loop circulation of water between the heating tanks and the two curing tanks. The curing tanks (Tanks Number 2 and 3) are made from double skin high-temperature-resistant glass-fibre between which is sandwiched an insulating layer of 50 mm polyurethane foam. The base of each tank incorporates 76 mm X 50 mm timber battens to carry weight of specimens being cured in tanks.

Galvanised, corrugated steel sheets are laid inside tanks for load distribution and also to protect the glass-fibre skin from accidental damage. Heating tank is made from 10 s.w.g. hot-dipped galvanised steel, insulation being provided by glueing 50 mm expanded polystyrene sheets onto the outside surface with a heat-resistant epoxy paste. Expanded polystyrene sheets 50 mm thick covered in polythene are used as insulating lids on all tanks.

Water is circulated around the system by three pumps. Two of them pump water from the heating tank into tanks numbers 2 and 3 one at a time. The water then returns under gravity flow from tank 3 via tank number 2 back into the heating tank. Pump 3 assists on returning water to the heating tank.

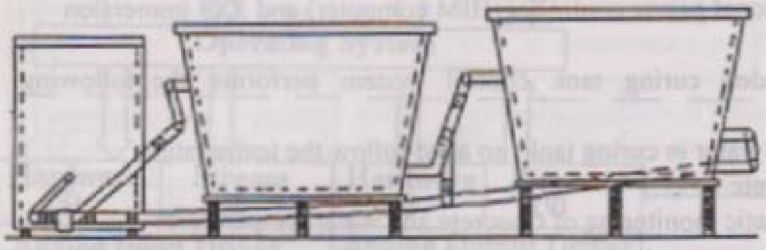
The heating tank is also connected to a chiller unit which, if required, allows the water to be pre-cooled to a starting temperature below ambient to match the starting temperature of freshly mixed concrete.

THERMOCOUPLE CONSTRUCTION AND CALIBRATIONS

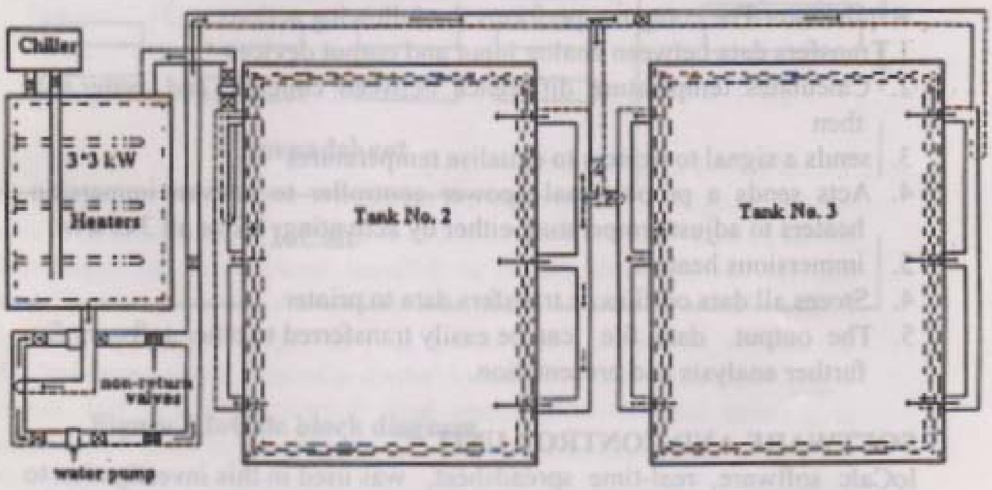
Type T thermocouples (Copper/Constantin) were used for temperature control. The required length of the thermocouple wire was cut and the PVC insulation surrounding the copper and constantin wires removed to a length of 60 mm from one end. The exposed wires were then twisted tightly at their tip and soldered using a special type T soldering wire. When a satisfactory bead (dot) was formed, it was cleaned with emery paper to remove any imputites.

The soldered measuring junction of the thermocouple was inserted in an open ended stainless steel tube until it had become exposed by approximately 60mm. The exposed end (40 mm) was then covered with a thick coating of Dow Coring 340 heat sink compound (This compound is very sensitive to temperature variations). The assembly was then pulled back into the tube, leaving at least 15mm from extreme end of the hollow tube. This end of the tube was then sealed with Belzona 1211 to avoid damage to thermocouples measuring junction from adverse conditions of the water. The other end of the tube was also sealed with Araldite and covered with a heat shrink to give a better protection and strength during the handling process

Calibration of thermocouples was made by measuring their outputs using a data precision 3600 digital voltmeter with a resolution of 1 μv within a working temperature of 0 °C to 60 °C. The measuring junction of thermocouple was subjected to same temperature range in steps of 5 °C using Techne DB-40L Dri-Block Calibrator with temperature stability of ± 0.05 °C. The reference junction was placed in a steel block and its temperature was measured by a calibrated thermometer which had



(a) Side view



(b) Top view

Figure 1 Details of the Curing Tanks

magnifying glass for accurate temperature reading. Thermocouples with output value within ± 1 μv as recommended by British Standard [14]. Part 5 were chosen for use in the Temperature Matched Curing System.

CONTROL, ANALYSIS AND DATA ACQUISITION

The upgraded system consists of the following components:

1. IBM micro-computer.
2. Thermocouple and analog input (PC 73) and output(PC 24) devices.
3. Proportional power controller (IBM computer) and 3X3 immersion heaters.

This upgraded curing tank control system performs the following operations:

1. Heating water in curing tanks so as to follow the temperature of concrete.
2. Auotomatic monitoring of Concrete and water temperatures

IBM MICRO-COMPUTER

The IBM micro-computer is used for central control, analysis and data acquisition. The computer performs the following actions:

1.Transfers data between analog input and output devices
2. Calculates temperature difference between concrete and water and then
3. sends a signal to heaters to equalise temperatures
4. Acts sends a proportional power controller to activate immersion heaters to adjust temperature either by activating 1,2 or all 3x3 kW
5. immersions heaters
4. Stores all data on files or transfers data to printer
5. The output data file can be easily transferred to other software for further analysis and presentation.

SOFTWARE AND CONTROL UNIT

loCalc software, real-time spreadsheet, was used in this investigation to read information from analog input and output boards into cells in spreadsheet. This information is used and updated at regular intervals to calculate and process experimental results.

Figure 2 shows diagrammatically the operation of loCalc and the general layout control unit.

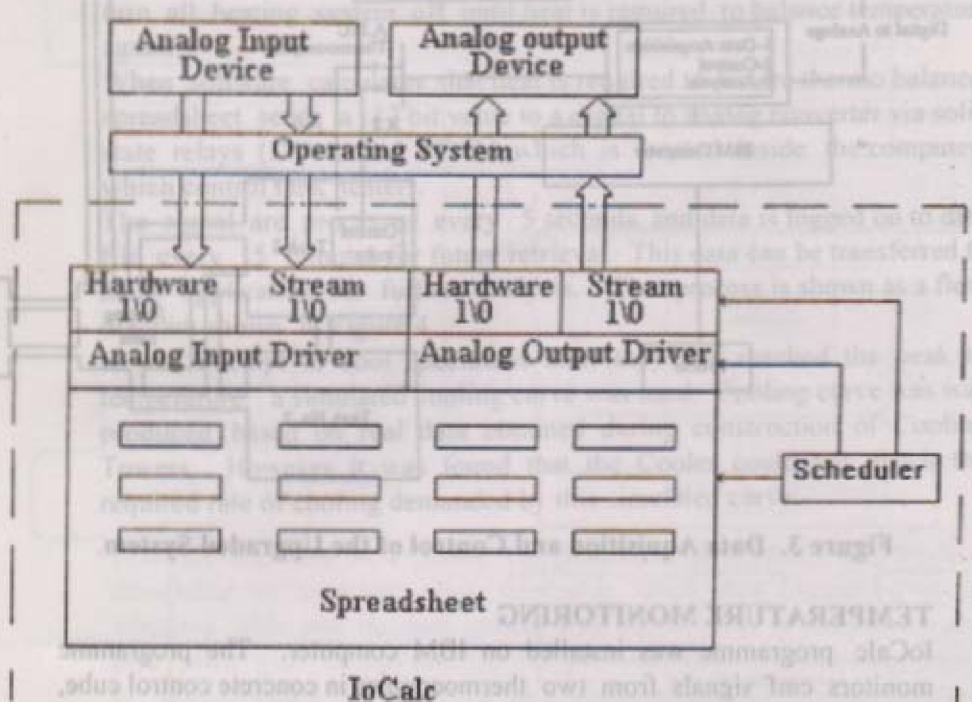


Figure 2 IoCalc block diagram

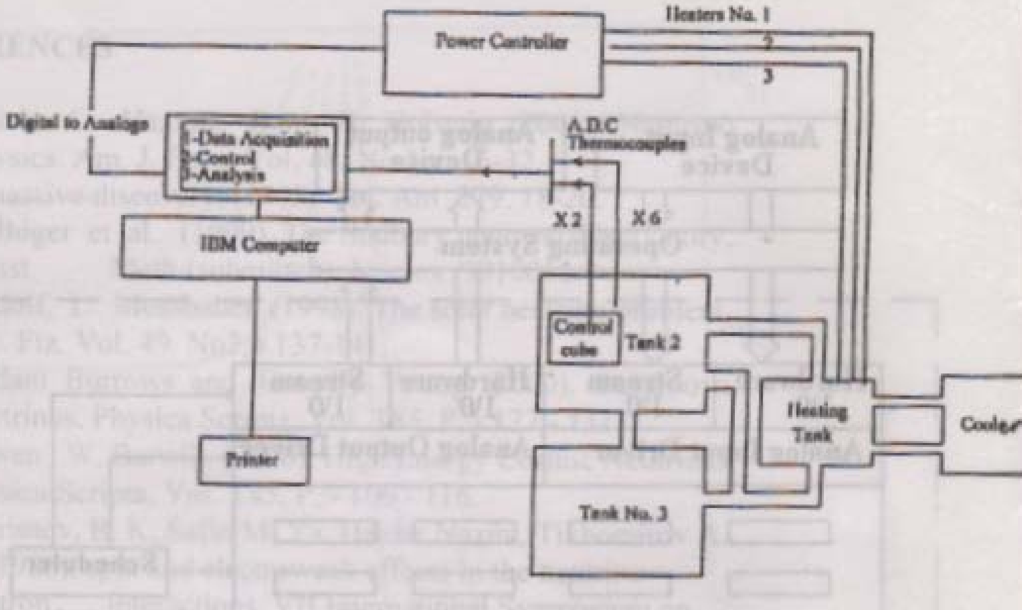


Figure 3. Data Aquisition and Control of the Upgraded System.

TEMPERATURE MONITORING

loCalc programme was installed on IBM computer. The programme monitors emf signals from two thermocouples in concrete control cube, and six thermocouple placed at different locations in the curing tank. Each value is placed in a separate cell in the spread sheet. The emf signals are converted from analog (μv) to digital signal by analog to digital converter (PC -73) board which is located inside computer. The programme then converts values from thermocouples (12 bit) to their respective temperatures in degree °C using a polynomial linearisation techniques (5th Order) and cold junction compensation which uses a solid state temperature sensor (LM 35=10μv/°C)

The programme then compares average temperature of tank with average control cube temperature. Three conditions are possible:

a)- Control concrete temperature is greater than the tank temperature

b)- Control concrete temperature is equal to tank temperature.

c)- Control concrete temperature is smaller than tank temperature.

In case (a) proportional power controller (Computer) measures difference in temperature between tank and control cube and decides accordingly on the quantity of energy needed to reinstate a balanced heat condition . This is achieved by controlling operation heating units (3*3 kW heaters) which can be operated individually or in conjunction.

In cases (b) and (c) computer acts as a proportional power controller to turn all heating system off until heat is required to balance temperature again.

When software calculates that heat is required to restore thermo balance, spreadsheet sends a 12 bit value to a digital to analog converter via solid state relays (D/A board PC 24 which is located inside the computer) which control tank heaters.

The signal are processed every 5 seconds, and data is logged on to data file every 15 minutes for future retrieval. This data can be transferred to many application for further analysis. The process is shown as a flow diagram shown in Figure 4

In , an attempt to cool specimens after they had reached the peak to temperature, a simulated cooling curve was used. Cooling curve was was produced based on real data obtained during construction of Cooling Towers. However it was found that the Cooler could not match the required rate of cooling demanded by this simulated curve.

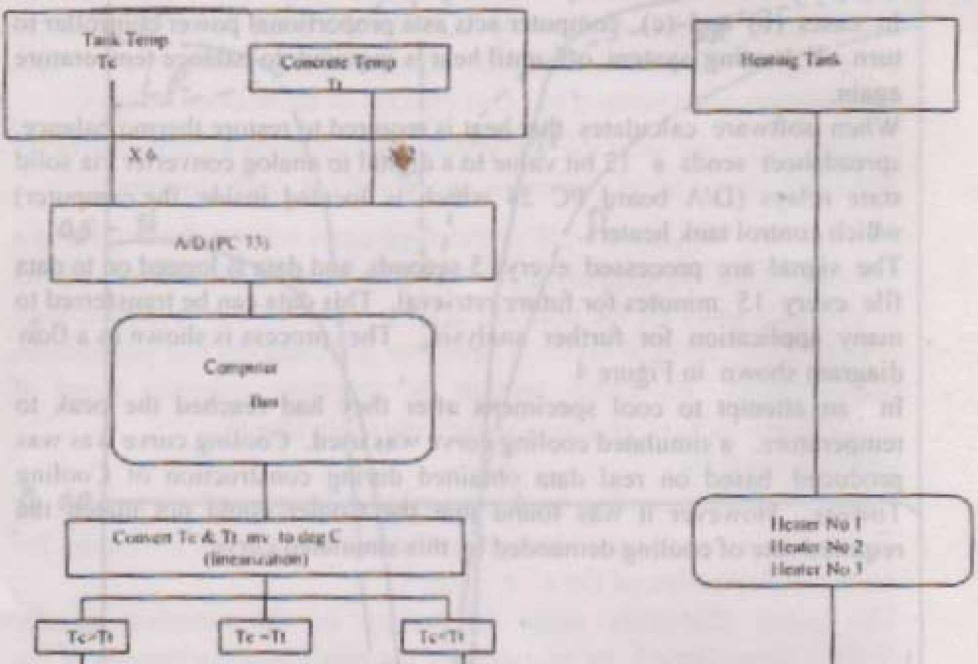


FIGURE 4 TEMPERATURE MONITORING FLOW DIAGRAM

EFFECT OF CURING CONDITION ON PERFORMANCE PARAMETERS OF CONCRETE

CONCRETE MIX PROPORTIONS CONCRETE MIXES

Mix type and proportion are given in Table 1. Concrete mix designed followed the method of minimum porosity proposed by Cabrera [15].

Table 1 Concrete Mix Proportion (by Mass)

Mix	OPC	PFA	Sand	Gravel	W/C ratio	Workability Slump(mm)
OPC	1	0	2.33	3.5	0.45	20
OPC1	1	0	2.33	3.5	0.55	55
OPC2	1	0	2.33	3.5	0.65	560
OPC/PFA1	0.7	0.3	2.33	3.5	0.55	55

*Flow Table value

CURING CYCLE

Concrete was cast in a plastic bag placed in the control box to ease demolding of concrete after hardening, and then compacted using vibrating table and the box sealed with plastic tape. A 300 mm copper pipe filled with oil was inserted into fresh concrete at a nominated point to accommodate the two thermocouples connected to temperature matched curing apparatus in order to measure temperature of the concrete to regulate water temperature in tanks.

In theory, under adiabatic conditions concrete temperature will reach a peak and remain at this temperature for an infinite period. However, in practice heat is lost from a concrete section and hence the temperature will cool to ambient. The time to cool will depend primarily on the geometry of the section formwork and time of striking. For the purpose of this investigation, on reaching peak temperature half of the specimens were left in water to cool naturally. On reaching ambient temperature, the specimens were transferred to 20 °C and curing continued until the specimen were required for testing. These concrete specimens were designated Type A.

The second half of the specimens were transferred to another tank whose temperature was similar to that achieved by different mixes to simulate the theoretical adiabatic conditions designated Type B. Figures 5 to 10 show control heating and cooling cycle of different concrete mixes investigated.

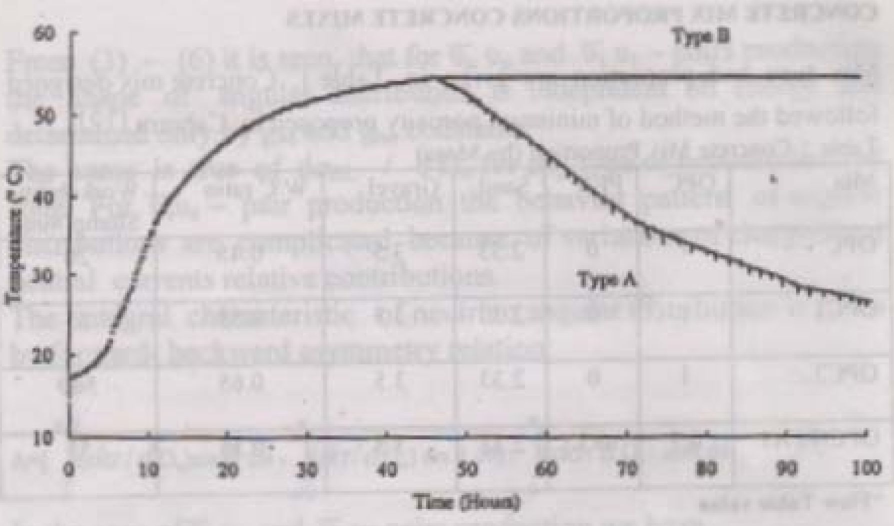


Fig 5 Temperature Profile for Mix OPC(w/c=0.45)

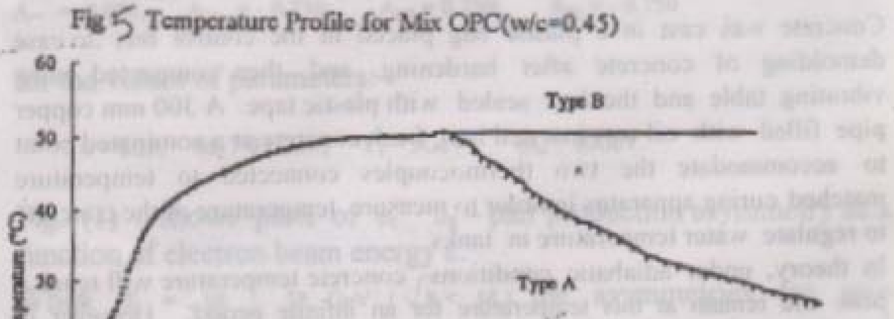


Fig 6 Temperature Profile for Mix OPC(w/c=0.55)

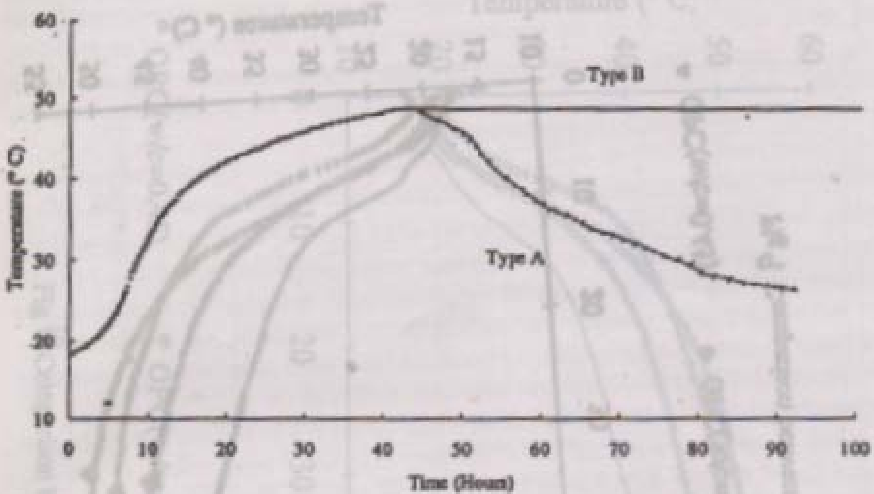


Fig 7 Temperature Profile for Mix OPC(w/c=0.65)

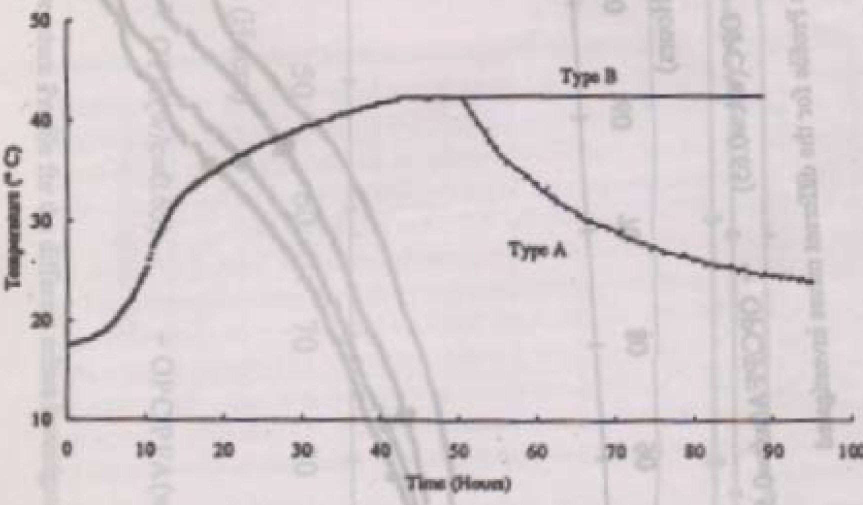


Fig 8 Temperature Profile for Mix OPC/PFA(w/c=0.5)

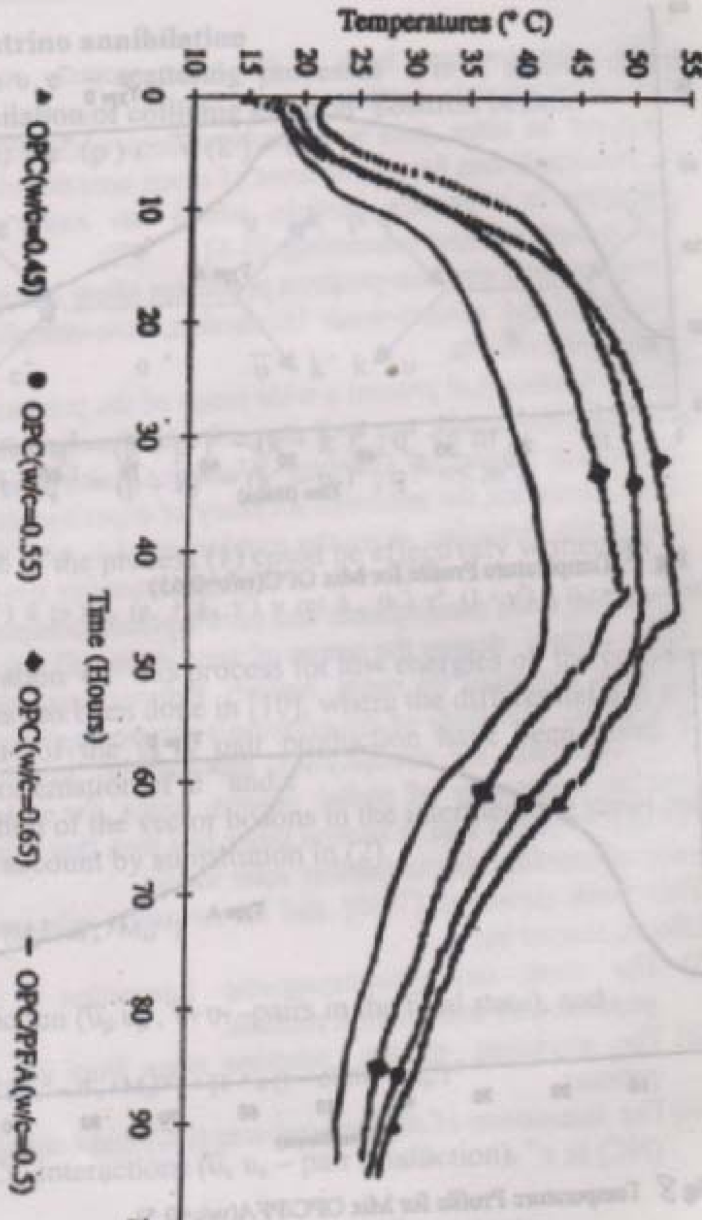


Fig 9 Comparison between Temperature Profile for the different mixes investigated (left to Cool Naturally)

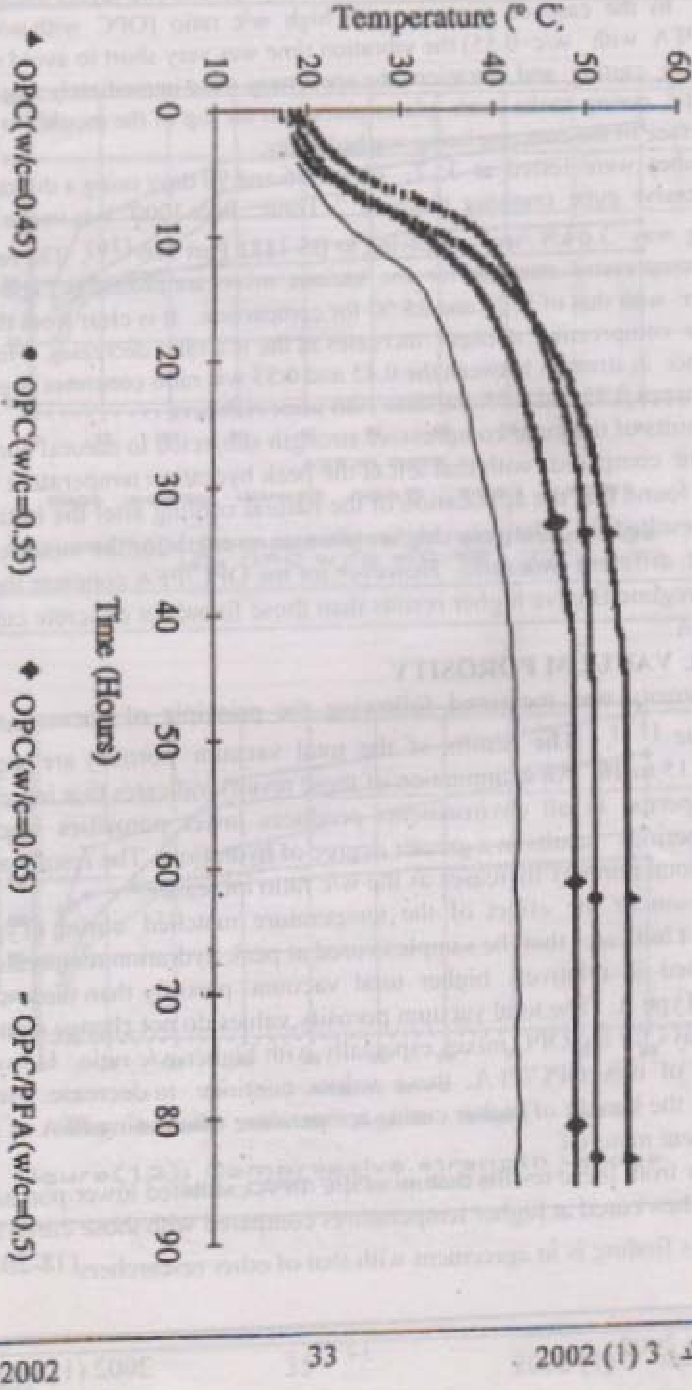


Fig 10 Comparison between Temperature Profile for the different mixes investigated

Cured at Peak hydration Temperature

COMPRESSIVE STRENGTH

The cubes were filled with concrete and compacted in two layers using a vibrating table. In the case of concrete with high w/c ratio (OPC with w/c=0.65) and OPC/PFA with w/c=0.55) the vibration time was very short to avoid segregation. After the casting and vibrations the specimens were immediately stacked into the adiabatic curing tanks with plates placed on the top of the moulds to prevent the top surface of the concrete being washed away.

The cubes were tested at 3, 7, 14, 28, 56 and 90 days using a digital automatic compressive cube crushing machine " Tonic Pact 3000" was used. The rate of loading was 3.0 kN /sec, complying to BS 1881 Part 116 (16). The results of the cube compressive strength for the various mixes are plotted in Figures 11 to 14 together with that of 5, 20 and 35 °C for comparison. It is clear from these results that the compressive strength increases as the w/c ratio decreases. However, the difference in strength between the 0.45 and 0.55 w/c ratio concretes is greater than that between 0.55 and 0.65. validate with some numbers.

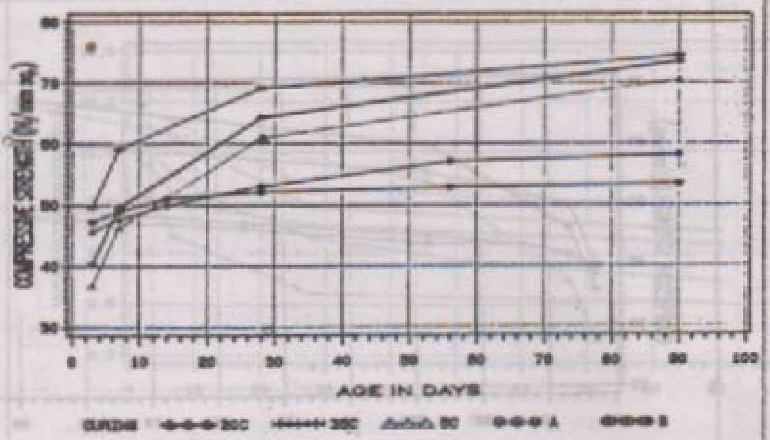
The results of the cube compressive strength subjected to natural curing (Type A) were compared with that left at the peak hydration temperature (Type B). It was found that the application of the natural cooling after the initial heating cycle resulted in relatively higher ultimate strength for the mixes containing OPC at different w/c ratio. However for the OPC/PFA concrete the strength under regime B gave higher results than those found for concrete cured under regime A.

TOTAL VACUUM POROSITY

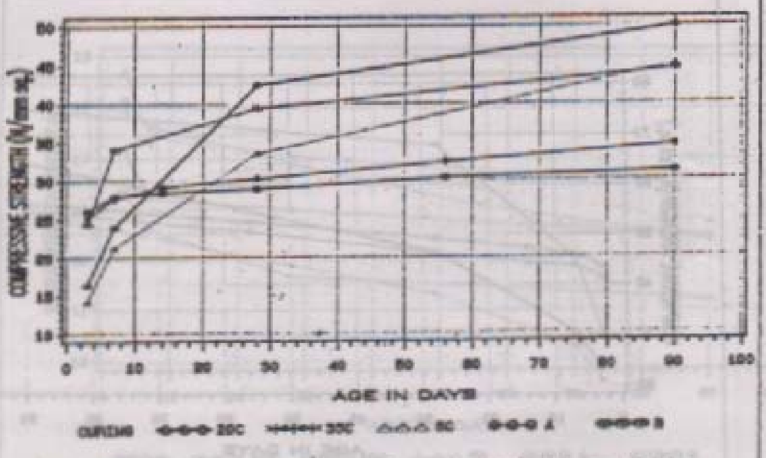
The porosity was measured following the principle of vacuum saturation technique (17). The results of the total vacuum porosity are presented in Figures 15 to 18. An examination of these results indicates that increasing the curing period in all environments produces lower porosities since longer curing periods results in a greater degree of hydration. The results also show that the total porosity increases as the w/c ratio increases.

Comparison of the effect of the temperature matched curing (Type A and Type B) indicates that the samples cured at peak hydration temperature(Type B) resulted in relatively higher total vacuum porosity than those subjected curing Type A. The total vacuum porosity values do not change significantly after 7 days for the OPC mixes especially with higher w/c ratio. However, for the case of mix OPC/PFA, these values continue to decrease. Hence this confirms the benefit of higher curing temperature when using PFA as a partial replacement material.

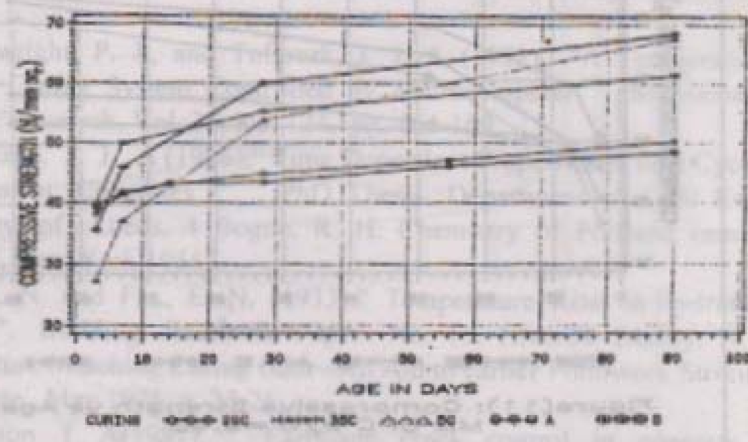
It is clear from these results that mix OPC/PFA exhibited lower porosity early in age when cured at higher temperatures compared with those cured at 5 and 20 °C, this finding is in agreement with that of other researchers(18-20).



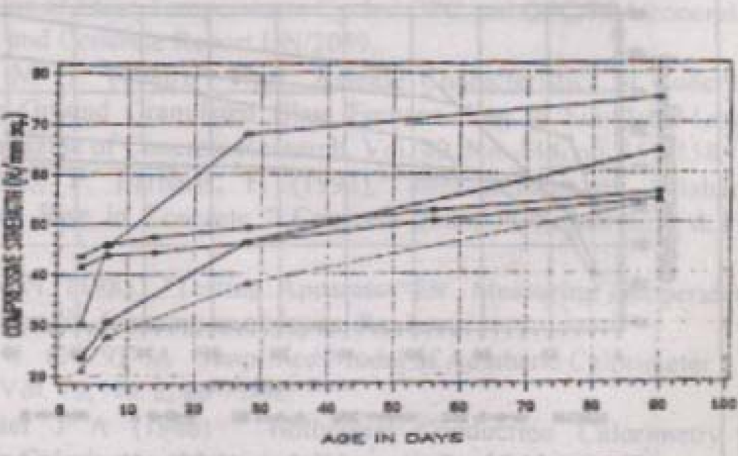
Figure(11): Compressive Strength vs Age
Mix OPC w/c =0.45



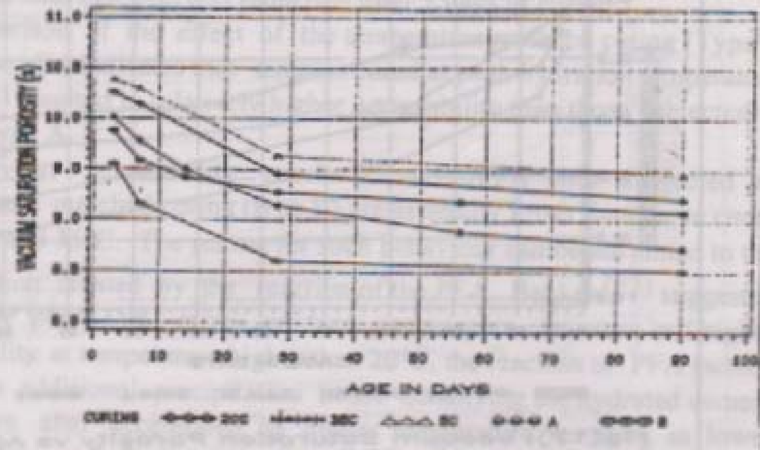
Figure(12): Compressive strength vs age
Mix OPC w/c =0.65



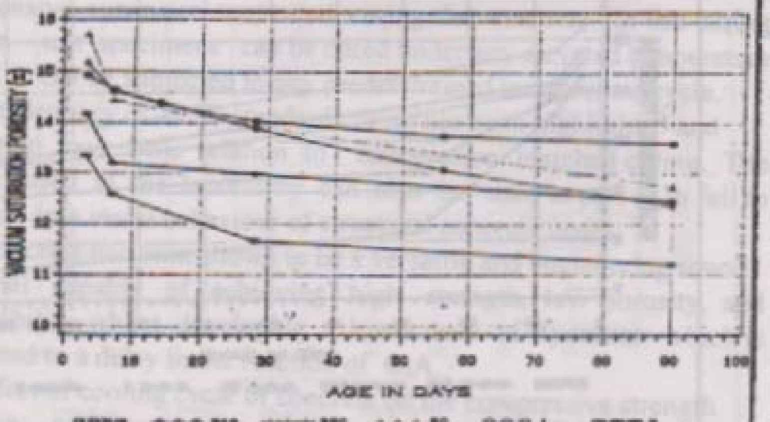
Figure(13): Compressive Strength vs Age
Mix OPC w/c =0.55



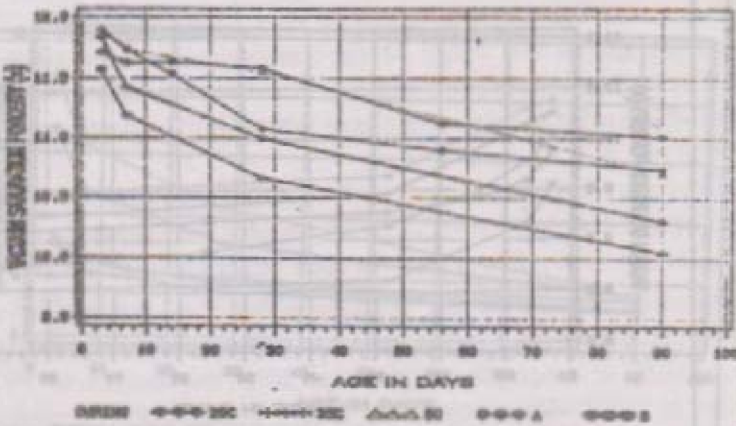
Figure(14): Compressive strength vs age
Mix OPC/PFA w/c =0.5



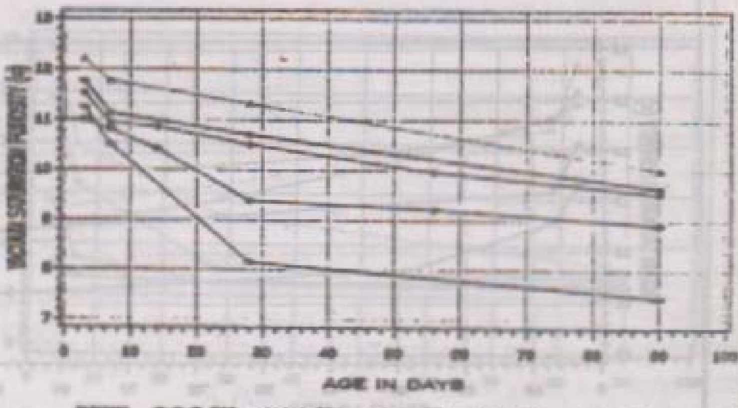
Fig(15): Vacuum Saturation Porosity vs Age
Mix OPC w/c =0.45



Fig(16): Vacuum saturation Porosity vs age
Mix OPC w/c =0.65



Fig(17): Vacuum Saturation Porosity vs Age
Mix OPC w/c =0.65



Fig(18): Vacuum saturation Porosity vs age
Mix OPC/PFA w/c =0.5

OXYGEN PERMEABILITY

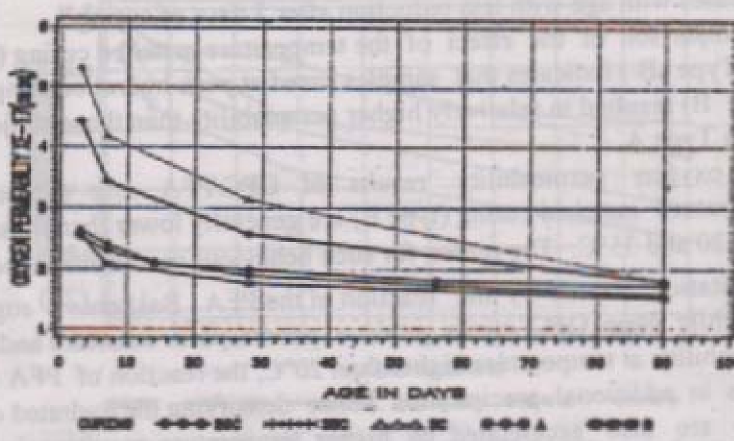
The oxygen permeability was measured using Leeds Permeameter[21]. Results of oxygen permeability are presented in Figures 19 to 22. The results for OPC concrete the permeability increases as the w/c ratio decreases with age with less reduction after 3 days of curing.

A comparison of the effect of the temperature matched curing (Type A and Type B) indicates that samples cured at peak hydration temperature (Type B) resulted in relatively higher permeability than those subjected to curing Type A.

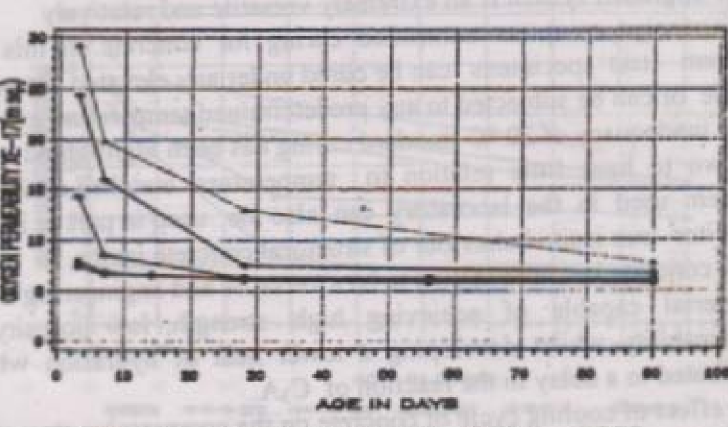
The oxygen permeability results of OPC/PFA mix subjected to temperature matched curing (type B) are generally lower than those cured at 5, 20 and 35°C. The reason for such behaviour can be attributed to the precipitation created by the reaction of the PFA. Bakker [22] suggested that while plain OPC mixes produce poorer pore structure and higher permeability at temperature higher than 20°C, the reaction of PFA (which results in additional precipitation hence densifying the hydrated cement paste) are also accelerated by higher temperature resulting in lower permeability and finer pore structure. These temperature accelerated precipitation of reaction of PFA can therefore compensate for physical poor hydrated OPC structures within samples at higher temperature.

CONCLUSIONS

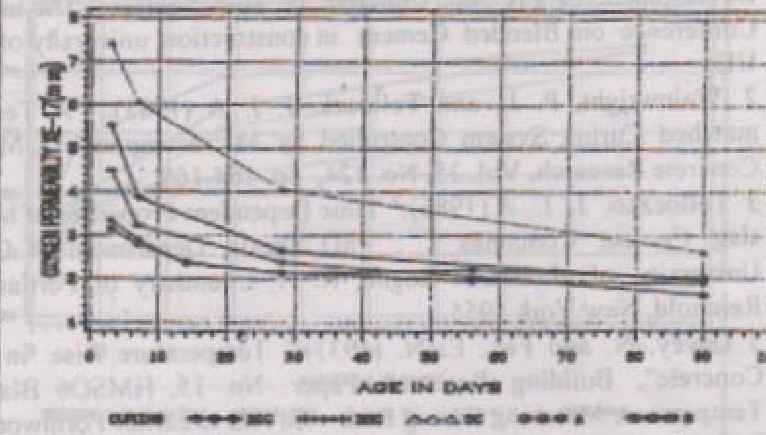
1. The upgraded system is an extremely versatile and relatively inexpensive computer controlled curing for concrete. In this curing system test specimens can be cured under any elevated temperature cycle or can be subjected to any predetermined temperature cycle.
2. The inadequacy of 20 °C standard curing has been highlighted and shown to have little relation to temperature matched curing. The system used in the laboratory can also be used in part or in full to monitor true insitu behaviour of structural concrete insitu.
3. PFA concrete has been shown to be a versatile and engineering sound material capable of achieving high strength, low porosity, and permeability whilst developing a lower heat of hydration which is attributed to a delay in the reaction of C_3A.
4. The effect of cooling cycle of concrete on the compressive strength porosity and permeability is clearly demonstrated in the light of presented results



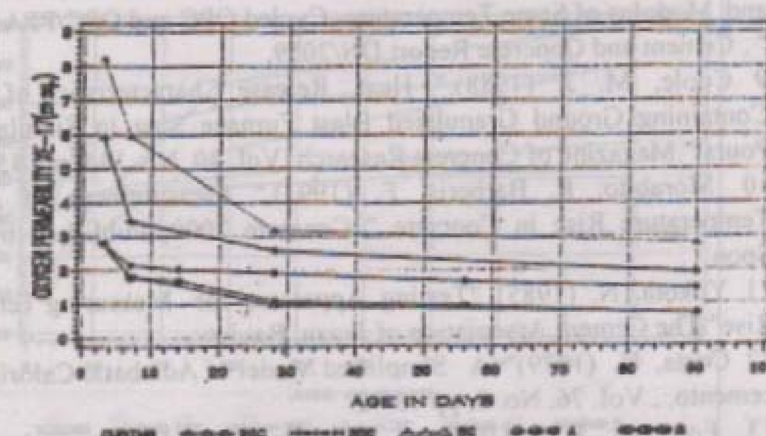
Figure(19): Intrinsic Oxygen Permeability vs Age
Mix OPC w/c =0.45



Figure(20): Intrinsic Oxygen Permeability vs age
Mix OPC w/c =0.65



Figure(21): Intrinsic Oxygen Permeability vs Age
Mix OPC w/c =0.55



Figure(22): Intrinsic Oxygen Permeability vs age
Mix OPC/PFA w/c =0.5

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