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COMPARATIVE THERMAL PERFORMANCE TEST FOR GGBS AND OPC CONCRETE MIXES.

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Abstract

The research investigates the effect of heating two concrete types and profiles to evaluate the most effective material during diurnal heating and cooling cycles.

Plain and finned concrete slabs were manufactured from concrete with a 100% - PC binder (CEM 1) and a binder using 50% - PC and 50% GGBS (CEM 111). The slabs were subject to mainly radiative heat for a 7.5 hour daytime period and left to cool for 16.5 hours.

Comparative readings were taken to measure the temperature difference between the two types of concrete during heating and cooling.

The findings showed concrete manufactured with GGBS had a lower heat build up and release when compared to concrete manufactured with 100% CEM 1 binder.

The research was limited to one comparative test at a single concrete strength with a single water cement ratio, and 50% GGBS cement replacement. Various GGBS cement replacement percentages could be tried to evaluate heat build up and release. Further research on U and Y values are also worthy of further investigation.

Thermal mass could be improved thus reducing the need to use energy intensive air conditioning systems.

Key Words: Ground granulated blast furnace slag, diurnal heating.

Introduction

The imperatives of climate change have led to a UK energy policy which is based on energy efficiency and low or zero carbon energy generation. UK policy recognises that buildings account for almost half of carbon dioxide emissions (Department of Trade and Industry, 2007). The Climate Change Act 2008, which gained Royal Assent in November 2008, includes a legally binding carbon reduction target of 80% by 2050 based on 1990 levels. If the UK is to

meet such a challenging target, the energy performance of buildings is a key area for improvement.

‘Society cannot exist without materials. They underpin everything we do and effect most areas of economic activity’ (DTI, 2006).

The Built Environment is heavily dependent upon materials. However,

‘Emissions of CO₂ from energy generation, with their role in climate change, represents perhaps the biggest environmental challenge facing the world today and materials play a significant part both in their production and mitigation’ (DTI,2006).

There is scope for reducing carbon dioxide (CO₂) emissions by using materials that have embodied energy and materials that have the potential to reduce running costs within buildings.

Many current UK construction techniques use concrete as a material, including the traditional “brick and block” approach in the domestic sector. “New” forms of construction have a slow rate of uptake in this relatively conservative industry sector. This is one reason for considering methods of improving the performance of concrete. In addition to the slow uptake of construction techniques using timber frame and SIP (structural insulated panels), there is the advantage of greater thermal mass for more traditional construction methods. This is of particular relevance to the non-domestic building sector, where thermal mass can be used to maximise the benefits of solar gain or passive cooling design. However, thermal mass may become increasingly important in a future climate change scenario in the UK of 2.3 °C to 5.3 °C increase in annual average air temperatures (Intergovernmental Panel on Climate Change, 2007).

This research project therefore looked at the thermal response of two concretes over a typical building heating and cooling cycle.

Method

The concrete mix design used throughout the research is shown in Table 1 and the process of mixture used for the manufacture of the test slabs is shown in Figure 1. The slabs were reinforced with a single layer of A142 fabric reinforcement placed centrally within the slab.

| Material | Quantities /m ₃ | CEM 111 concrete slab | | CEM 1 concrete slab |
|-----------------------------|----------------------------|-----------------------|-------------------|----------------------------|
| Sand | 780kg/m ₃ | 780kg/m ₃ | | 780kg/m ₃ |
| 10 – 20mm Aggregate | 1030kg/m ₃ | 1030kg/m ₃ | | 1030kg/m ₃ |
| Cement content | 365kg/m ₃ | 365kg/m ₃ | 182.5 kg CEM 1 | 365kg/m ₃ CEM 1 |
| | | | 182.5 kg GGBS | |
| Water cement ratio was 0.68 | | Slump 50 mm ± 5 mm | | |

Table 1: Concrete mix design.

The design mix for the CEM 111 slab was composed of concrete using a binder consisting of ground granulated blast furnace slag (GGBS) as a 50% cement replacement. The design mix for the CEM 1 slab was concrete using 100% ordinary CEM 1 as a binder.

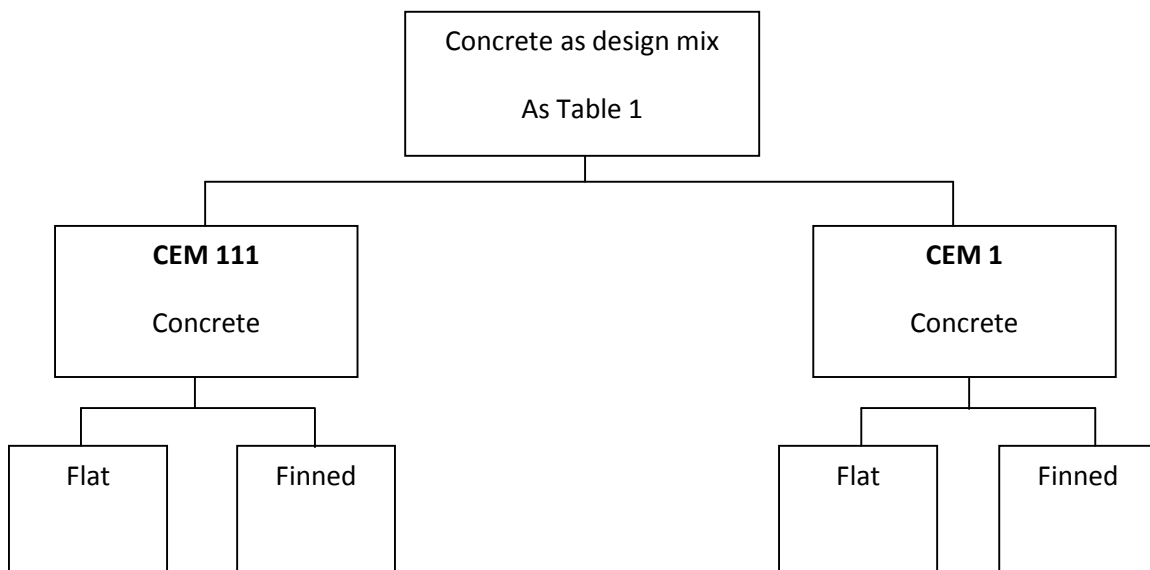


Figure 1: Manufacture of test slabs.

With regard to slab manufacture; four sets of formwork were constructed: two finned and two flat (see Figure 2). The sets of formwork were made from plywood and the fins were made from soft wood formers that were fixed in the bottom of each required set of formwork. Prior to casting the concrete, each set of formwork was coated with mould release oil.

Four concrete test samples were cast and these comprised of two flat slabs and two finned slabs. One flat and one finned slab were cast with CEM 111 and one flat and one finned slab were cast with CEM 1. Each slab contained a concrete volume of 0.036 m³ with a flat rear surface area of 600 mm x 600 mm. Both concrete mixes were mixed using a rotary drum mixer, batch CEM 111 was used to fill two moulds one flat and one finned and batch CEM 1 was used in the same manner. All of the concrete mixes were compacted in the formwork for equal periods of time using a vibrating table and a tamping bar.



Figure 2: Formwork for test slabs.

A matrix of 4 mm diameter drill holes (see Figure 3) at different depths of 20, 40 and 60 mm were drilled in the back of each slab at 28 days after casting. The holes are colour coded on Figure 3, red for 20 mm, green for 40 mm and yellow for 60 mm deep. Each hole was filled with grease in order to provide a point of thermal contact such that temperature readings could be taken with a hand held thermocouple.

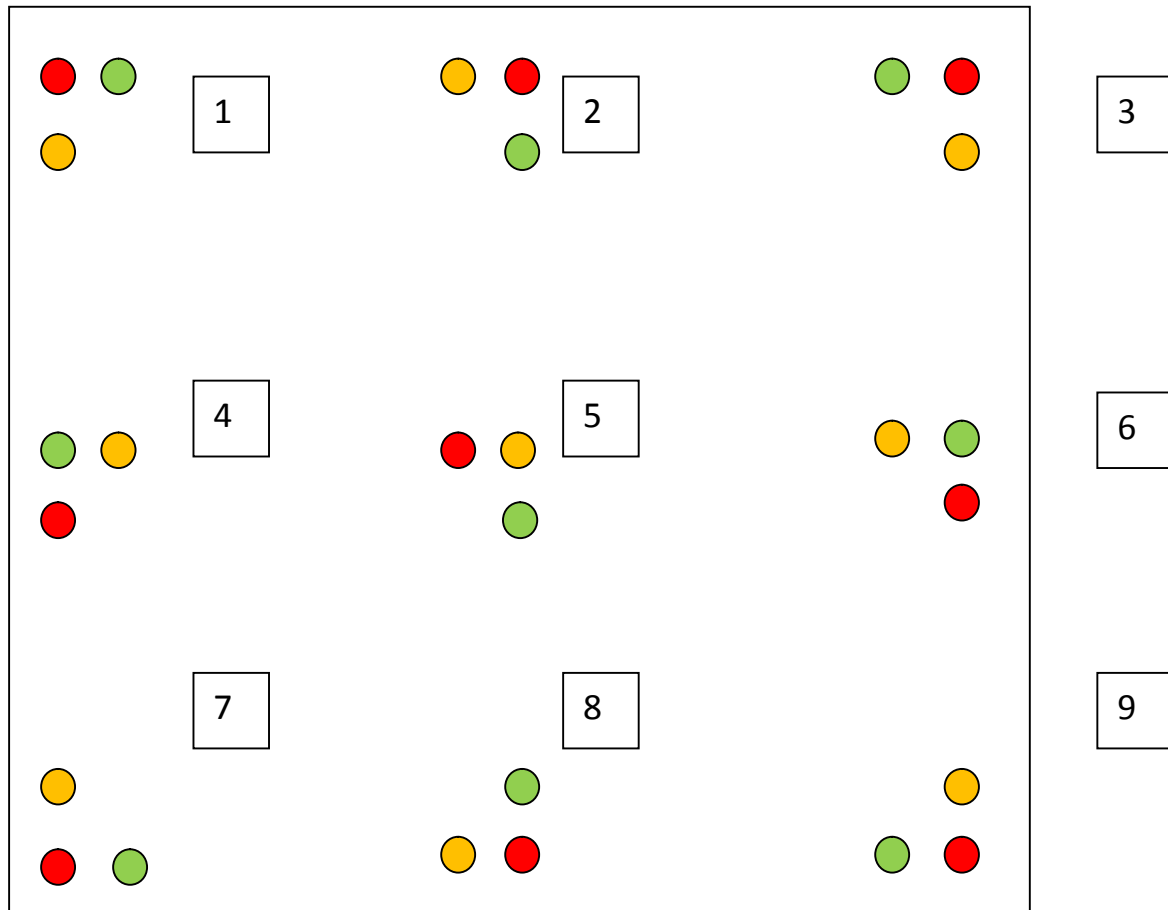


Figure 3: Plan view of slab - Probe Hole Location

Two slabs were suspended, each above a radiant 3kW Red Rad heat source. The heat source was chosen to provide convective and radiative heating (a greater fraction of heat output was radiative, than convective for this heat source). The two slabs of the same mix were suspended and tested together. An aluminium access tower with tubular steel structural supports was used to take the weight of the slabs that were suspended by two 2.5 mm high tensile steel ropes per slab. The dimension between the underside of the slab and heater was 250 mm at 90° to the heat source (see Figures 4 and 5).

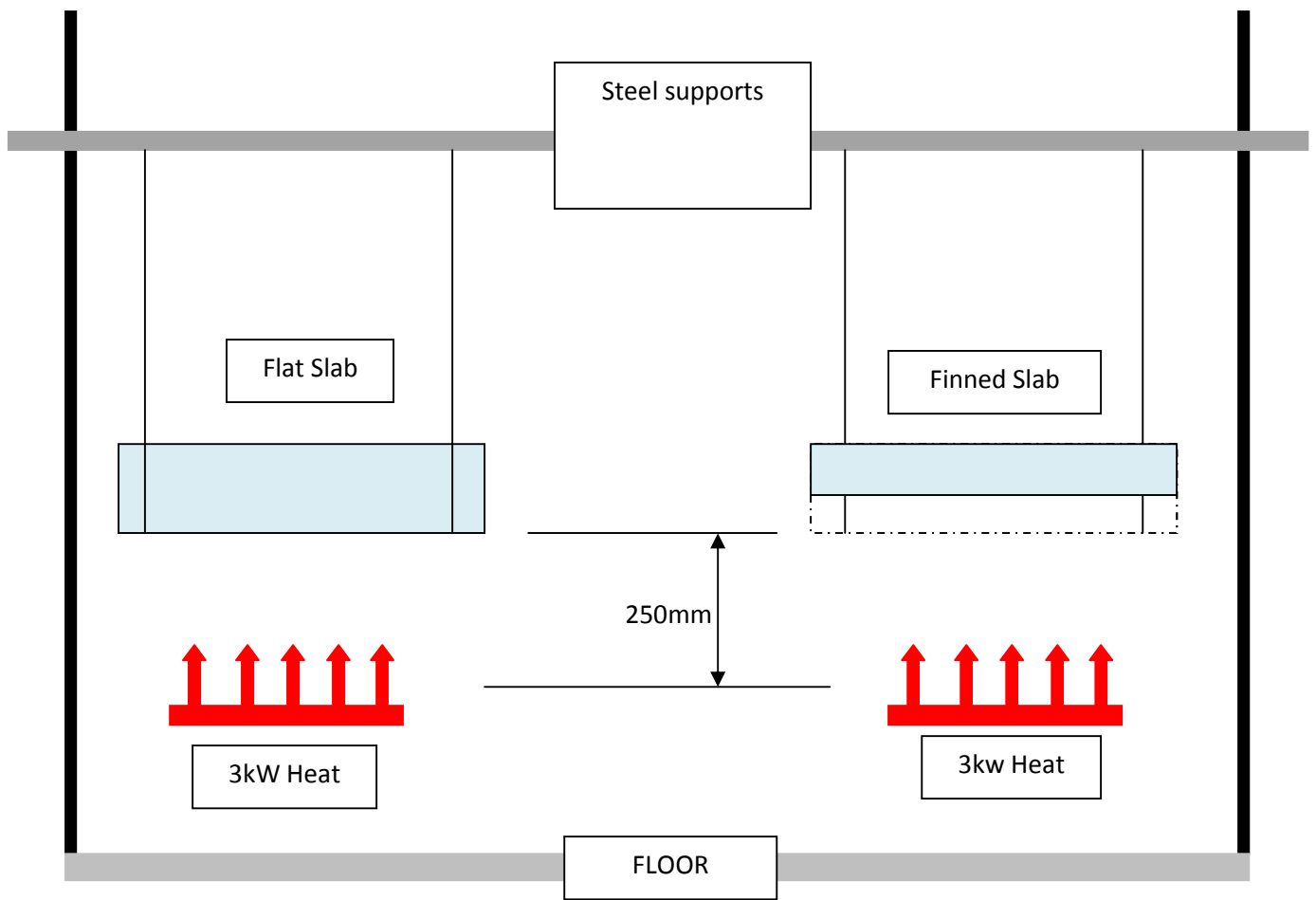


Figure 4: Test Rig Design – Cross sectional view

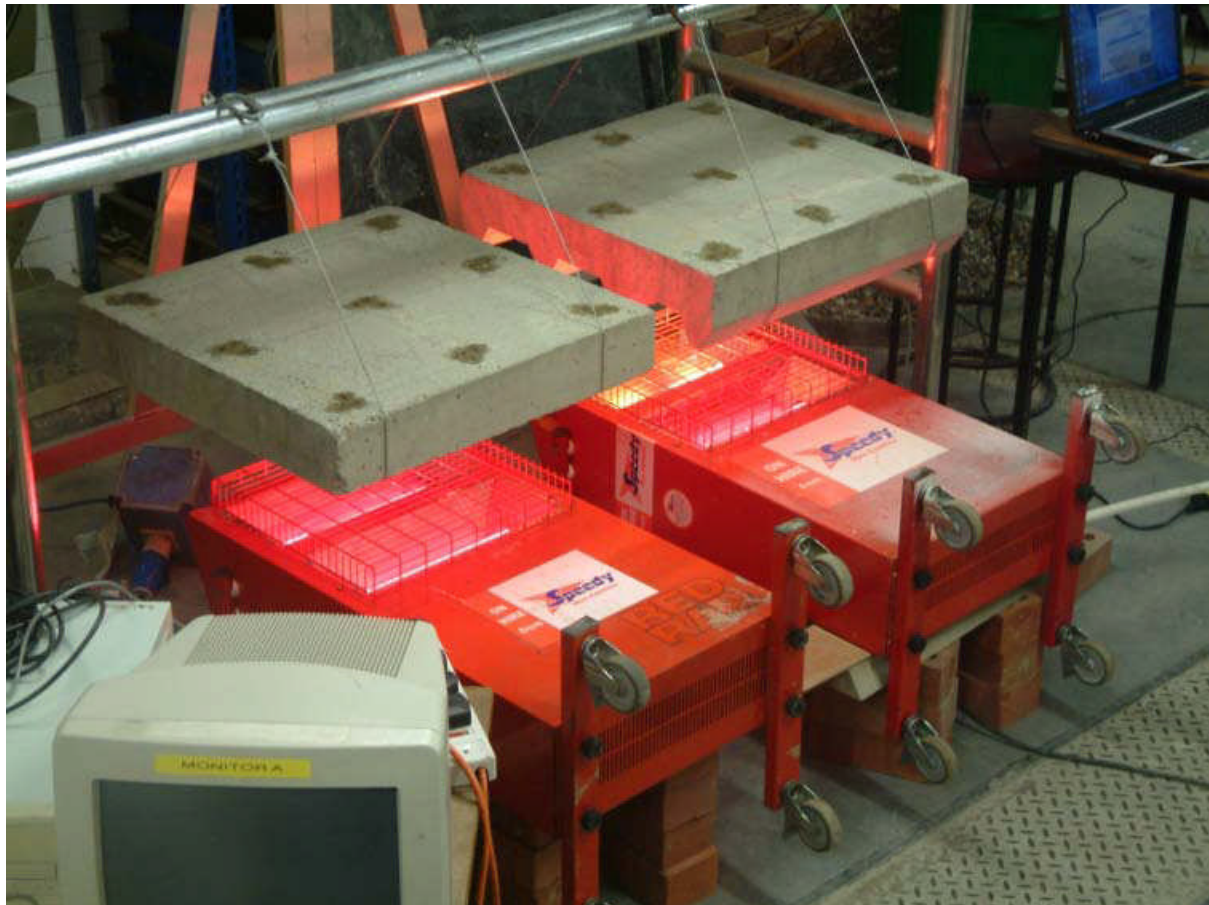


Figure 5: Test rig in operation.

At 9.00 am the heaters were turned on and a full set of temperature readings were taken – a thermocouple was used to record the ambient room temperature

Surface temperatures nearest the heat source were recorded using a hand held thermocouple. A thermocouple linked to a 'k' type data logger was also used to obtain the temperature from each drill hole. A prescribed method of taking readings was used, starting at position one (Figure 3) then working around each drill hole group numbered 1 to 9. The group of temperatures were measured every 30 minutes between 9.00 and 16.00 hours. The accuracy of the thermocouple readings were within $\pm 1^{\circ}\text{C}$.

At 16.30 the heaters were switched off and a separate set of temperature readings were taken. The temperatures were recorded for the period between 17.00 and 8.30, using thermocouples connected to the same data logger. The data logger was connected into a laptop which recorded temperature measurements every 30 minutes. Thermocouples were used to record temperature; three in each slab at position five, and one was used to record the ambient room temperature.

Results

After batching and air curing for 28 days, the slabs were weighed and density calculated. The density of the slabs is shown in Table 2. The mean density of the four concrete slabs was 2417 kg/m³ and the maximum variation from the mean was 2.7%. relating to the CEM 111 flat slab. The remaining slabs were in the region of 1% of the mean density. Density can influence heat flow, however the slabs were considered suitably similar for testing purposes.

| Slab Identification | Dry Mass (kg) | Re-measured Volume (m ³) | Total Surface Area (m ²) | Density (kg/m ³) |
|---------------------|---------------|--------------------------------------|--------------------------------------|------------------------------|
| CEM 111 flat | 80.8 | 0.034 | 0.94 | 2376 |
| CEM 111 finned | 80.6 | 0.033 | 1.054 | 2442 |
| CEM 1 flat | 80.1 | 0.033 | 0.92 | 2427 |
| CEM 1 finned | 80.0 | 0.033 | 1.050 | 2424 |

Table 2: Density of concrete slabs

The data collected from the tests is shown in Figures 7 (CEM 111) and 8 (CEM 1). The surface temperature is higher on both concrete types using a finned profile when compared to a flat profile.

An interim temperature check at three hours was recorded in Figure 6 showing the relative performances of CEM 111 and CEM 1 concrete slabs..The CEM 111 slab showed a general tendency to absorb less heat than the CEM 1 and this was due to the use of GGBS having lighter colour.

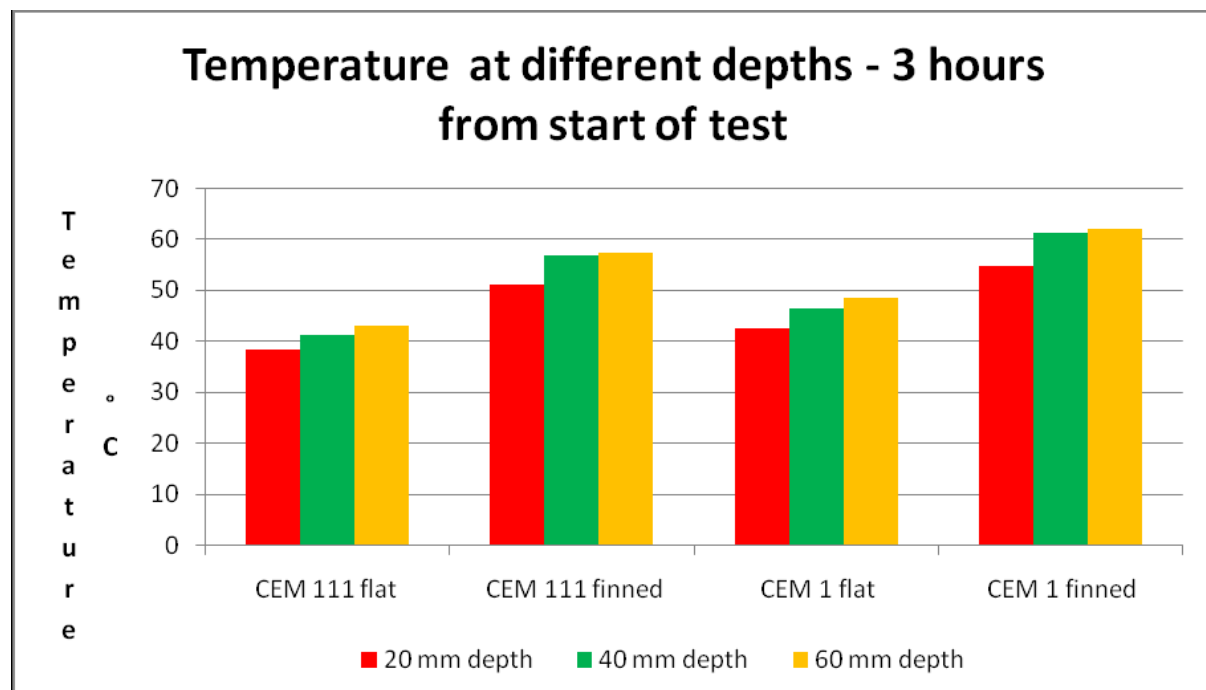


Figure 6: Temperature within concrete slabs after 3 hours of heating.

When measured at three hours the mean internal temperature difference between flat GGBS and CEM 1 cements was 5 °C which equates to a 12% temperature decrease when GGBS is used.

The finned profile slabs show a 4.3 °C temperature difference between the CEM 111 mix and the CEM 1 mix, which shows GGBS when used in concrete has a lower temperature.

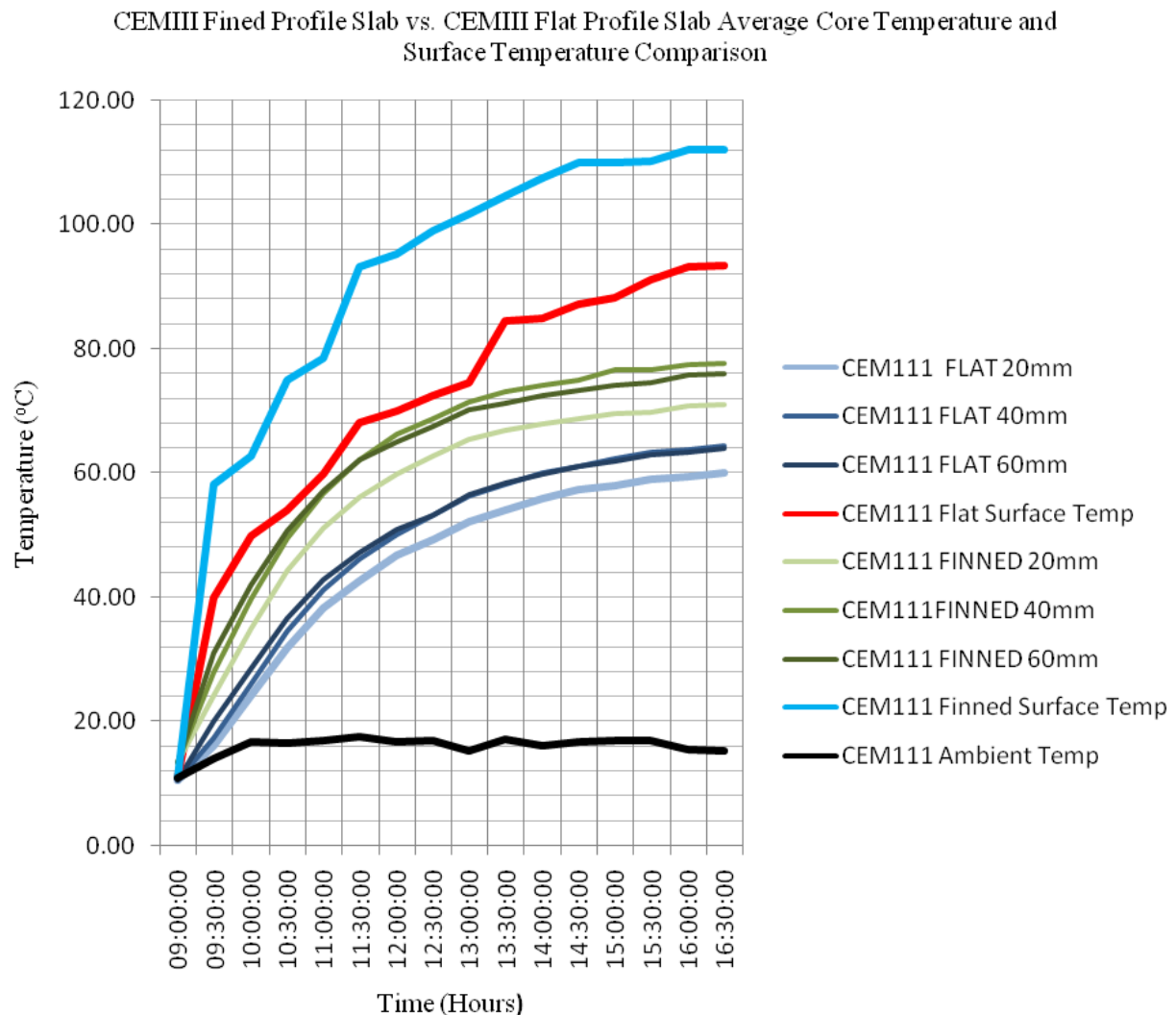


Figure 7: Temperature measurement at depth and surface for flat and finned slabs (CEM 111)

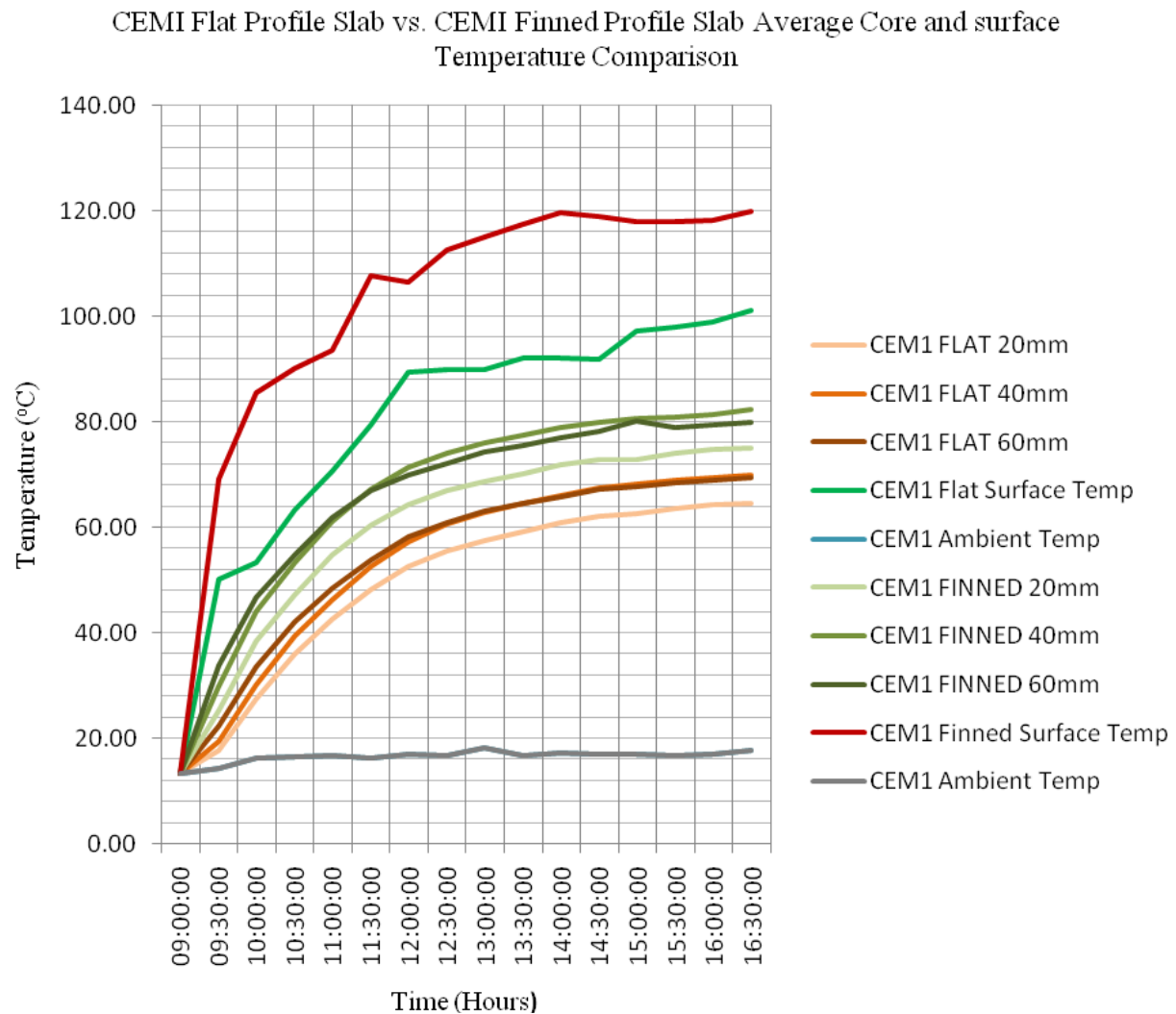


Figure 8: Temperature measurement at depth and surface for flat and finned slabs (CEM 1)

In Figures 7 and 8 the plot of the 60 mm depth temperature showed a slightly lower than expected final value when compared to the 40 mm plot. This was thought to be due to losing contact grease from the 60 mm holes at a greater rate than the 40 or 20 mm holes. A possible reason for this was the absorption of grease by the concrete due to the melting of the grease at high temperatures following three to four hours of heating. Loss of grease would lead to a loss of thermal contact between the concrete and thermocouple. This effect was not observed before 3 hours of heating

Figure 9 shows the heat build up and release over a twenty four hour period, the area under the graph indicates the amount of heat released to the surroundings. The plain and finned concrete CEM 1mix released heat most rapidly, whereas the CEM 111 mix had a slower heat release.

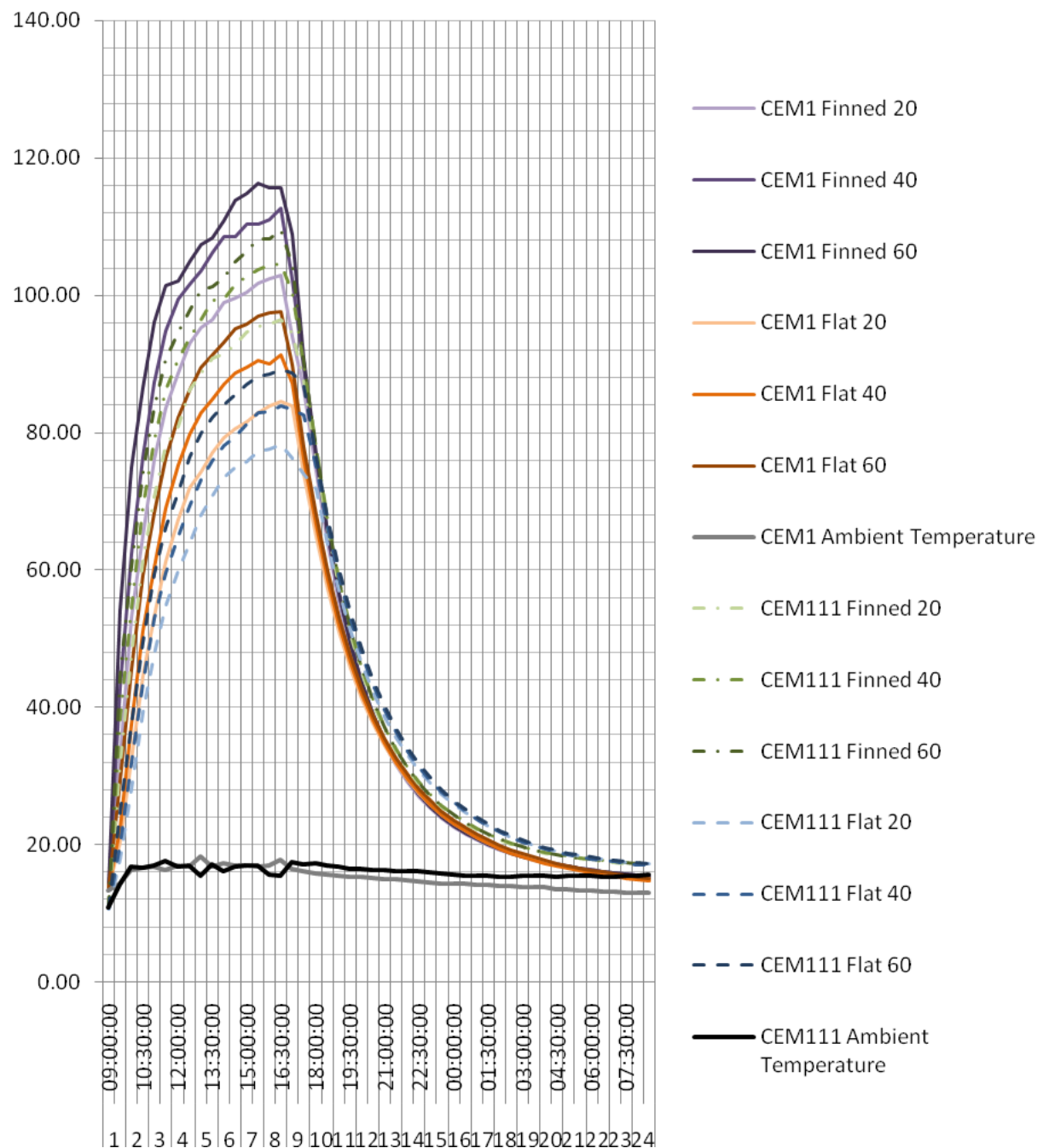


Figure 9: Maximum heating and heat release results over 24 hours

Each slab dissipated on average 50% of the heat within three hours and 75% of heat within the six hours of the cooling period.

Figure 9 identified that, all four slabs dissipate heat similarly, however the CEM 111 mix flat and finned slabs released heat from the slabs at a slower rate than the CEM 1mix flat and finned slabs. This is a significant finding with regard to internal climate control as the heat is stored longer within the slab and dissipated into the room overnight to provide an even temperature. This will potentially reduce the need for additional overnight heating.

The final surface temperature of the finned slabs, show that CEM 1 - PC has a slightly higher surface temperature (3%) than CEM 111 - GGBS, at the end of the test. The findings are not significant, however the CEM 111 mix does have a slightly lower tendency to absorb heat as shown in Figures 6, 7 and 9.

The final surface temperature of the CEM 1 flat slabs is 9% higher than the concrete manufactured with CEM 111, therefore concrete manufactured with CEM 111 has shown to have a lower propensity for heat absorption.

Conclusions

The research presented here has investigated the impact of use of a by product cement replacement on the thermal behaviour of concrete. One concrete mix used CEM 1 as a binder, whilst the second mix replaced 50% of the cement binder with a ground granulated blast furnace slag (CEM 111). The response of the cast concrete to a typical UK heating and cooling cycle was recorded, results showed that the concrete with cement replacement heated

and cooled at a slower rate. The lighter colour of concrete with GGBS (CEM 111) was effective in reflecting radiant heat to a greater extent than CEM 1. A change to the response factor of the material may be due to a change in the thermal transmittance, U, and admittance, Y. This is worth further investigation. As the concrete was cured to 28 days, it is likely more free water would be present in the pore structure of the concrete manufactured from CEM 111. This may have affected the temperature recorded in the CEM 111 slabs and evaporation may have cooled the slabs slightly during the heating process, although this is not considered to be significant. A repeat test would be valuable if the concrete was cured over a period in excess of 56 days prior to testing to negate the free water effect.

Two geometrical surface shapes were considered, a flat surface and a finned surface. The finned surfaces showed a faster heating a cooling rate, for both concrete mixes. The increase in surface area for the finned surface increased the total amount of heat gain and heat loss to the concrete slab by convection and radiation. Only one concrete mix variation was used with the cement replacement, and further investigation may be useful in determining the optimum balance of physical and thermal performance based on the proportion of ground granulated blast furnace slag.

If future building structures are to retain concrete as a building material, results indicate that use of a ground granulated blast furnace slag as a cement replacement may increase the thermal mass of a building. This construction material may therefore be of benefit for buildings which are designed with high thermal mass to reduce internal temperature swings.

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