CURING REGIMES NECESSARY FOR THE PRODUCTION OF TOP QUALITY CONCRETE PAVING BLOCKS AT MINIMUM COST

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SUMMARY

The manufacture of concrete block paving is very competitive and highly automated. The demands on the product, structurally, visually and in terms of durability, are high.

The semi-dry concrete used in the manufacture of concrete paving blocks is dangerously near the 'too dry' side of the water/cement ratio curve. It is therefore necessary to prevent evaporation of the water in the products.

Pulverised-fuel ash and Ground Granulated Granulated Blastfurnace Slag are used by manufacturers to reduce costs and improve product performance. Both of these materials have low early strength and require elevated temperatures (up to 40°C) to provide the process benefits.

Control of temperature and humidity - a controlled curing regime - is the key to the manufacture of consistent high quality concrete block paving at minimum cost. This paper describes the key process parameters and practical solutions used in the industry.

1. INTRODUCTION

The manufacture of concrete paving blocks, particularly in the UK and Western Europe, is very competitive. This leads manufacturers to seek ways to reduce costs and improve product quality.

Quality in terms of Concrete Paving Blocks is defined as:

Meeting the National Standard in all respects - consistently.

Achieving a good surface finish - not too open textured.

Making products with bright attractive colours.

Making products with consistent colour and low levels of efflorescence - ideally none.

Costs are reduced by reducing production and raw material cost by:

Using high volume automated plant.

Running these plants for as many hours as possible - typically 18 hours/day.

Using shortest cycle times.

Using more economical raw materials.

Costs are also reduced by bette process control - i.e. control batching, mixing, water content, moul filling, compaction and curing Tighter process control means tha margins can be reduced.

This means:

Using less of the most expensive materials - primarily cement and pigment.

Ordinary Portland Cement (OPC in the text) can be substituted by other, cheaper binders.

2. OPC SUBSTITUTION BY CHEAPER BINDE

2.1 UK Practice

In the UK all products conform to B 6717 - Precast Concrete Pavi Blocks.[1] This British Standard wa issued in 1987 as a development of th previous standard produced by th industry and users.

BS 6717 specifies that:

'The binder content of the compacted concrete shall not be less than 380 kg/m³.'

Permitted binders include:

Ordinary Portland Cement to BS 12.[2] (OPC in the text).

Portland Pulverised-fuel ash cement to BS 6588. [3]

Portland-blastfurnace cement to BS 146 Part 2. [4]

Pulverised Fuel-ash to BS 4892: Part 1. [5] (PFA in the text).

Ground Granulated Blastfurnace Slag to BS 6699. [6] (GGBS in the text).

2.2 The benefits of using PFA and GGBS as binders:

PFA and GGBS are generally added separately to the mix at the time of batching.

Because there is a need to use high levels of binder (380kg/m³) and because OPC is a relatively expensive material there are major cost reduction opportunities by using a significant proportion of PFA and GGBS as substitutes for OPC. Although GGBS itself is not that much cheaper than OPC, because of its light colour it is possible to reduce the pigment proportion and/or to make brighter, lighter colours.

Additionally both PFA and GGBS reduce efflorescence because they combine with free lime as hydration proceeds.

PFA, because of its spherical shape, improves the workability of the mix - giving easier (and quicker) mould filling and improves the compactibility and cohesion of the concrete. Surface finish is also improved

For these reasons high volume producers use significant volumes of PFA and/or GGBS in concrete paving blocks.

2.2 European Practice

Blended cements are not as common in the UK as in mainland Europe. Most European manufacturers use blended cements which react in the same way as PFA or GGBS added separately.

3. EARLY STRENGTH GAIN (UP TO 28 DAYS) OF CONCRETE CONTAINING PFA AND GGBS AS BINDERS

It is well known that the early strength development of concrete containing significant proportions of PFA and GGBS as binder is slower than that of a mix containing only OPC. This is a major disadvantage in using high proportions of these materials in concrete block paving manufacture. The figures below illustrate the typical early strength gain relationship an ambient temperatures.

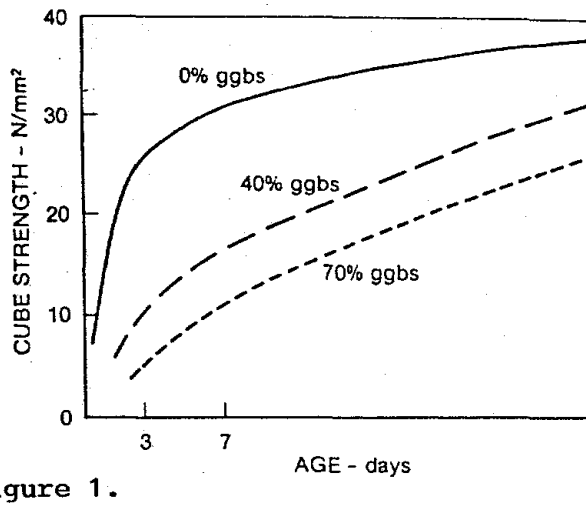


Figure 1.

The relationship between Strength a Age for a GGBS composite concrete equal binder content and workability 20°C. [7]

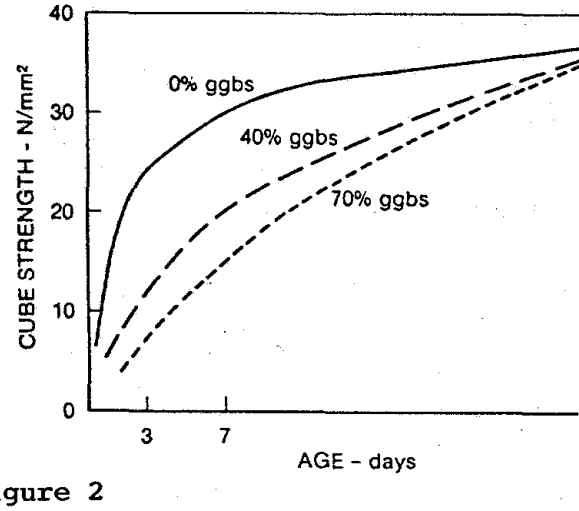


Figure 2

The relationship between Strength Age for a GGBS composite concrete equal 28 day strength and workabil at 20°C. [7]

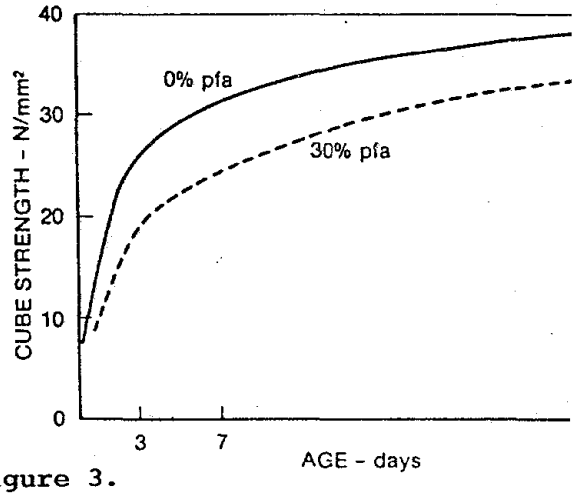


Figure 3.

The relationship between Strength Age for a PFA composite concrete equal binder content and workabilit 20°C. [7]

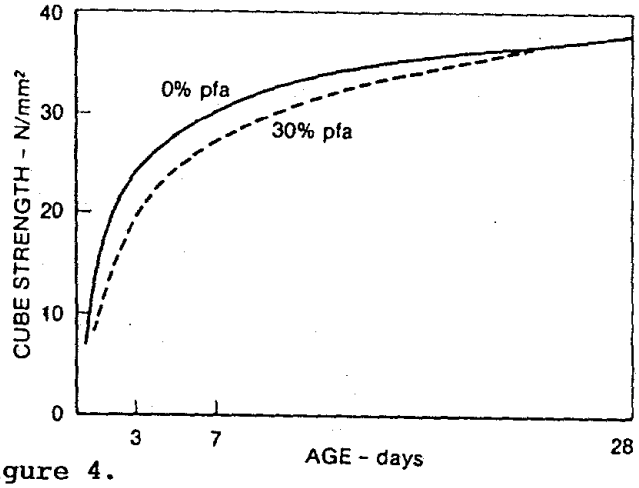


Figure 4.

The relationship between Strength and Age for a PFA composite concrete of equal 28 day strength and workability at 20°C. (7)

In order to improve the early strength gain of PFA and GGBS concretes it is necessary to increase the temperature of the concrete. This is achieved by warm curing - illustrated in Figure 5.

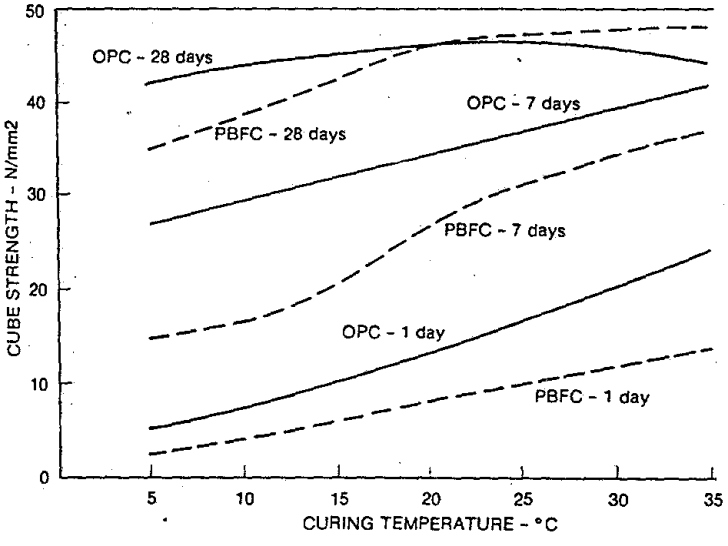


Figure 5.

The relationship between Strength and Age for PFA and GGBS composite concretes of equal binder content and workability at varying temperatures. (7)

IT CAN THUS BE SEEN THAT IN ORDER TO USE SIGNIFICANT PROPORTIONS OF PFA AND GGBS AS, COST REDUCING, CEMENT SUBSTITUTES IT IS NECESSARY TO CURE CONCRETE AT ELEVATED TEMPERATURES.

4. WATER/CEMENT RATIO AND CONCRETE BLOCK PAVING MANUFACTURE

Concrete sets because of hydration - a chemical reaction between the binder and water. This chemical reaction needs a precisely defined water/cement ratio,

Too little water - and not all binder will react to form cementitious paste. Too much water the crystal formation within concrete will be less than ideal. the excess water will be left wi the concrete as capillaries and p making the concrete porous and durable.

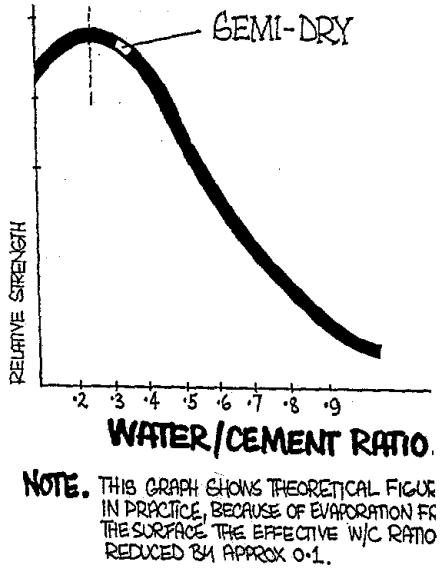


Figure 5: The relationship between water/cement ratio and strength. (8)

5. SEMI-DRY CONCRETE USED IN BLOCK PAVING MANUFACTURE

Theoretically the concrete is still the 'too wet' side of the curve. practice, because of the evaporat from the block surface it is necessa to use as much water in the mix possible to fully hydrate the binc and generate as much strength possible.

The maximum water content is limited the process - vibratory compaction - special purpose block machines.

The limiting factors are:

Concrete sticking to the tampe heads.

The filler box becoming heavil encrusted with concrete.

Difficulty in filling the moul cavities.

Product slump (or collapse) afte demould.

Products falling out of the botto of the mould (multilayers only).

IT IS THEREFORE NECESSARY, IN PRACTI TO PUT AS MUCH WATER IN THE CONCRETE PERMITTED BY THE CONSTRAINTS OF PROCESS.

AFTER MANUFACTURE AS MUCH WATER MUST BE RETAINED (PREVENTED FROM EVAPORATING) AS POSSIBLE.

6. CURING REGIMES - PROCESS PARAMETERS

Control of temperature and humidity levels for the initial period after manufacture is called curing.

It has been shown above, that to manufacture minimum cost quality semi-dry products requires elevated temperatures and low evaporation. This is achieved by a controlled curing regime. This is a key area of the manufacturing process where sophisticated companies have the edge.

In practice, it is only possible to keep concrete paving blocks in a controlled curing regime for 24 to 72 hours. However, if the curing conditions for this initial period are optimised, blocks can be produced at minimum cost and high quality.

6.1 Temperature

Figure 5 shows that the higher the ambient temparature, up to say 40°C, the better. Above this temperature shrinkage and other deleterious effects can occur. In practice, if the temperature in the curing regime can be maintained in the region of 35°C to 40°C, the trade off of manufacturing cost reductions against capital and heating cost appears to be about right.

6.2 Humidity

The humidity needs to be maintained as high as possible without saturation - at least 95% R.H.

At no time must the humidity be allowed to rise to 100% R.H. This would result in condensation in the curing chamber with a risk of drips landing on the products. This would cause unacceptable surface damage.

6.3 Time

The products need to stay in the curing regime for as long as practicable. At least 24 hours and if possible 72 hours. The longer the products remain in the warm humid environment the more PFA and GGBS can be used. Additionally, because after 3 days in the curing regime the products will have attained 60% to 80% of their 28 day strength the local outside ambient temperatures will then have less influence on 28 day strength.

It is important that the products do not freeze during this period.

6.4 Stratification - laterally and vertically

As concrete cures the heat liberated the hydration reaction will natura increase the temperature of concrete and its surround environment. Hot air rises, and if steps are taken the top of the chamb will become much hotter than bottom.

Additionally, because most systems h doors at one end or both ends of rac heat and humidity can escape at e end of the racks.

Ideally some form of forced circulation is necessary to ensure t temperature amd humidity stays const at all points in the curing chambers

6.6 Insulation

The racks should be well insulated the outside. Each rack, or group racks, should be insulated from neighbours. Insulation performa should be specified so that condensation can occur at the hotte most humid conditions with the cold ambient temperature.

Insulation of curing chambers must executed carefully. No cold brid must occur. Ingress of colder ambi air must also be minimised.

6.7 Curing capacity

It is advantageous to keep produ inside the curing regime for as long possible. The longer the products at elevated temperatures and h humidity the more potential for cem replacement, control of colour efflorescence and the lower production margin.

There are significant savings heating costs if the products ren in the curing regime as long practicable. After the products h started to hydrate and the exother temperature rise has become establis it is possible to switch off exter heat so that the products can 'cook their own juice'.

7. PRACTICAL SOLUTIONS

7.1 Manufacturers without racks or chambers

At least, manufacturers should c products with polythene sheets minimise evaporation and pre surface drying - although this cause efflorescence and other vi defects. If the factory building

heated to provide satisfactory working conditions this can be reasonably successful.

7.2 With racks and chambers - unheated

Chambers should be insulated well - as specified above. Doors, themselves insulated and fitted with good seals, should be fitted to each chamber - or (less preferable) a group of chambers.

The floor can be wetted - some manufacturers use troughs on the floor containing water to raise the humidity level.

This simple type of system can bring the following problems:

Stratification of humidity and temperature in the chamber. Hot air rises - and stays there. The uppermost products are hotter and therefore cure faster - thus aggravating the problem.

In cold weather the product may be only just above freezing point. The reaction at these low temperatures is slow and heat generation (by hydration) insufficent to kick the process off. Thus some initial heat is desirable.

This process is not controlled. This means variability in strength, colour and potential efflorescence.

7.3 With racks and chambers - heated

Many methods of putting heat into the chambers are suitable. Water or oil filled pipes (finned and plain) and direct gas firing are all used. The radiators or ducting should be below the lower shelves in the chambers. This has the benefit that the heat will rise through the products. Unless care is taken the humidity will fall and the products will dry out - very deleterious.

7.4 With racks and chambers - heated and humidified - with forced slow air movement

This is a fully controlled curing regime. Warm (40°C), very humid air is distributed throughout the chamber at low velocity.

Suitable heating and humidification systems, with chamber by chamber control are provided. Doors are automatic and close as soon as the chamber is full. The design of the air circulation system is such that no blocks are subject to fast moving streams of air. Stratification and dead spots should be minimised by careful design.

Alternatively, the whole of the curing is carried out in one large insulated chamber with zoned heating with thermostatic control. This then reaches a steady state. The temperature is largely constant without air movement because the chamber is so well insulated and the heat is applied at floor level. The doors are automatically controlled such that air movement is minimised.

The control system can be programmed to boost the temperature initally and then reduce - often to zero - the heat input as the exothermic reaction takes over. The temperature/humidity cycle should be developed to give the best results.

8. CONCLUSION

The high volume manfacture of concrete paving blocks is a highly automated process. The demands on the product, structurally, visually and in terms of durability, are high.

Controlled curing regimes ensure that quality standards can be maintained - and improved - whilst reducing manufacturing costs. This makes concrete paving blocks more competitive against competing pavement surfacing systems.

REFERENCES

1. British Standards Institute. Specification for Precast Concrete Paving Blocks. BS 6717:Part 1 1986

2. British Standards Institute. Specification for Ordinary and Rapid Hardening Portland Cement. BS 12 - 1978

3. British Standards Institute. Specification for pulverised-fuel ash cement. BS 6588 - 1973

4. British Standards Institute. Specification for Portland Blastfurnace Cement. BS 146:Part 2 - 1985

5. British Standards Institute. Specification for Pulverised-fuel ash for use as a cementitious component in structural concrete. BS 3892:Part 1 - 1982

British Standards Institute. Specification for Ground Granulated Blastfurnace Slag for use with Portland Cement. BS 6699 - 1986

T.A. Harrison and D.C. Spooner. The properties and use of concretes made with composite cements. Cement and Concrete Association - Interim Technical Note 10 - 1987

A.M Neville. Properties of Concrete. 1981. ISBN 0 273 01642 3. pp. 269 - 279