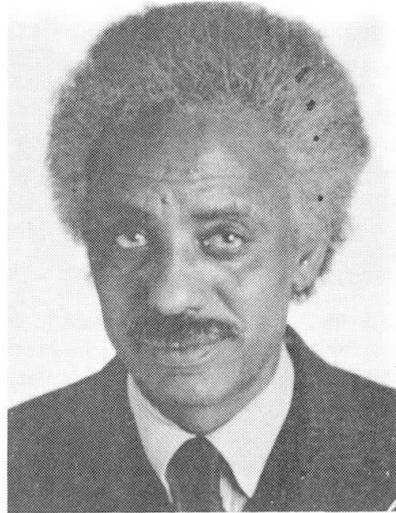# Proper Use of High-Alumina Cement Concrete

Utilisation correcte d'un béton avec un ciment à haute teneur en aluminates

Korrekte Verwendung eines Betons mit Hochtonerdezement

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SUMMARY

After a two year period of storage, the reduction in HACC (High-Alumina Cement Concrete) compressive strength, indicated zero and 50% for normal and dry curing conditions respectively. Full conversion after 7 days hot water storage produces a 25% strength reduction. Under normal curing conditions, the flexural strength developed increased at a curing temperature of 22.5 °C as compared to the standard 18 °C. Shrinkage in HACC is of the same order as that of PCC (Portland Cement Concrete) for similar storage periods, while swelling is independent of storage temperature. In slow converted specimens, creep is dependent on the mineralogy or morphology of the hydrates, while full conversion leads to the same order of creep as PCC.

RÉSUMÉ

Après un temps de stockage de deux ans, la réduction de résistance à la compression du béton HACC a atteint zéro et 50% pour des conditions de conservation du béton normales, respectivement à sec. Un changement complet après 7 jours de stockage en eau chaude donne une réduction de résistance de 25%. Dans des conditions normales de conservation la résistance à la flexion qui se développe a augmenté à une température de conservation de 22.5 °C, comparée à la température normale de 18 °C. Le retrait dans le béton HACC est du même ordre que celui observé dans le béton CP pour un même temps de stockage, alors que le gonflement n'est pas affecté par la température de stockage. Pour les spécimens à changement lent, le fluage dépend de la minéralogie ou morphologie des hydrates alors qu'un changement complet mène au même ordre de fluage que le béton CP.

ZUSAMMENFASSUNG

Nach einer Lagerungszeit von zwei Jahren, erwies sich der Abfall der Druckfestigkeit von Hochtonerdezement als Null und jeweils 50% für normale wie trockene Erhärtungsbedingungen. Vollständige Umwandlung nach 7 Tagen Warmwasserlagerung erbringt eine 25%ige Festigkeitsreduktion. Unter normalen Erhärtungsbedingungen nahm bei einer Erhärtungstemperatur von 22.5 °C im Vergleich zu der Standardtemperatur von 18 °C die entwickelte Biegefestigkeit zu. Bei ähnlichen Lagerungszeiträumen erfolgt Schrumpfung des Hochtonerdezements in gleichem Umfang wie für Portlandzementbeton, während die Quellung von der Lagerungstemperatur unabhängig ist. Bei langsam erstarrenden Proben ist die Kriechdehnung von der Mineralogie oder Morphologie der hydraulischen Bindemittel abhängig, während das vollständige Erstarren zu gleichen Kriechdehnungen wie bei Portlandzementbeton führt.

1.   INTRODUCTION

High-alumina cement is produced by heating a mixture of limestone and bauxite to fusing, which quickly attains a very high strength and is in its original form sulphate resistant. At hydration meta-stable aluminates are found at normal temperature and humidity crystalizing in hexagonal form which in turn transforms into a stable cubic compound. Such chemical transformation, depending on intensity of temperature and humidity, induce reduction in volume of gel and increase porosity, termed as "conversion", resulting in strength reduction.(1)

Research that went into high-alumina cement (HAC) was rather unimpressive, to say the least, and consequently code provision accorded by CP114, CP116 and CP110 to HAC in buildings was rather unsatisfactory and misleading. The highlight of this, among other things, was the collapse of two beams of the roof over the swimming pool of Sir John Cass Red Coat School at Stepney, London.(2). Consequently, the part relating to HAC in CP110 was deleted in 1974. With this realization the author conducted intensive studies from 1975 onwards on the subject with special emphasis to prestressed concrete out of which a portion is hereby presented.

2   CONCRETING AND INSTRUMENTATIONS

Short and long-term studies of standard tests running to maximum two and a half years on cylinders, cubes and flexural prismatic beams were made using destructive and non destructive tests. To simulate different environmental conditions, the following curing storages were procured: normal curing (21.5°C and 90-95%RH), dry curing (18°C and 45%RH) and hot-water curing (45°C and 100%RH). One day after cast in an open laboratory area (temperature varying from 7°C to 27°C) the specimens were carried to respective storage regimes.

A 100mm x 100mm x 1000mm prismatic beam steel moulds, fabricated at the School of Civil and Structural Engineering Dept., University of Bradford, UK, were prepared for making shrinkage and/or swell and creep specimens. Shrinkage and creep rigs, fitted with electrical and mechanical measuring devices to avoid instrumentation breakdown, were also designed and fabricated to suit storage conditions.

A mix design, 1:1.6:3, with free W/C ratio of 0.35, aggregate cement ratio of 4.6, compaction factor of 0.78 and cement content of 4100 n/m^3 of concrete was employed throughout the experimental period. The overall grading of aggregates, as suggested by Newman (3), conformed to zone No 2. d.t.a. tests were run periodically to determine the degree of conversion for the various storage regimes. Petrological analysis on sands, for possible presence of soluble alkalis, and spot checks on British brand HAC chemical composition were also performed.

3   TEST-RESULT ANALYSIS AND CONCLUSIONS

3.1 Compressive strength.

The 24-hour strength was nearly the same for all concrete cast, with mean strength of 82.8N/mm^2. Fig.1 indicates the strength - storage time curves for all regimes.

3.1.1 Normal storage: specimens stored in wet room, with indicated ambient conditions, reveal an increase in strength development except in a situation where slow conversion
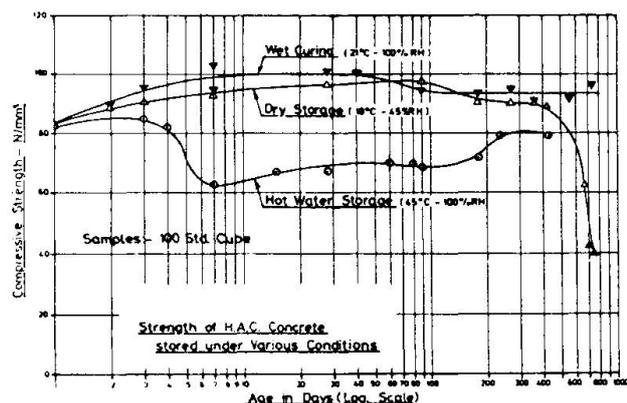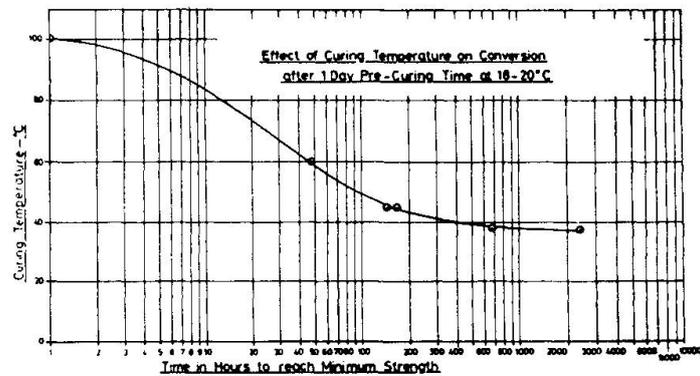

FIG. 1

takes place the fall is followed by strength recovery emanating from rehydration of the unhydrated cement. Such phenomenon persists for a length of time until the chemical reaction is complete. That is to say a cyclic behaviour, characterised by sag and hog, dominates until the hexagonal aluminates (CAH_{10}) complete transformation into the more stable cubic aluminates (C_3AH_6) is restored. It follows that such sluggish conversion does not lend itself to appreciable reduction in strength; evidently not lower than the 24-hour strength.

3.1.2 Hot water storage: specimens stored in hot-water tanks indicate slight increase in strength up to 3 to 4 days and a rapid fall is recorded after 7-8 days. Full conversion time can be estimated using Fig.2, curing temperature versus time required for specimens to reach full conversion. The curve is (Fig.1) then picks up strength gradually, a clear indication of rehydration followed by conversion of the fresh hydrated cement. The maximum observed loss of strength is in the range of 25% of the 24 hour strength. Hence steam curing could offer the best solution if HAC is employed in buildings for tropical climate.

FIG. 2

3.1.3 Dry storage: Specimens stored in dry conditions, Fig 1, received the most damage. After 400-day storage in dry room rapid deterioration without sign of strength recovery is observed. After 750 days the compressive strength was reduced to 50% of the 24 hour strength. Deterioration of high-alumina cement concrete, as some researchers claim, cannot always be attributed to conversion. In this particular case, after one day curing in an open laboratory area, specimens were stored in dry room. It is expected that, with the harsh mix the specimens received and denied of the proper curing for the crystals to mature, strength development to full capacity would be far remote. It is also possible, due to severe specimen exposure they may have lost some of the water of hydration vital to matured crystal formation. Destructive tests showed that bond between paste matrix and gravel was exceedingly weak with subsequent loss in strength. The degree of conversion obtained for these specimens also supports that conversion alone had little to play in the deterioration.

3.2 Flexural strength of Standard Prismatic Beams.

Fig.3 shows flexural strength versus time curves for all storage regimes. These curves are similar in shape as that given by Fig.1. The significant change occurs for normal storage condition in which strength development is more pronounced than the remaining storage regimes. This leads to the conclusion that normal curing temperature for HACC can best be established at about 22°C in lieu of the accepted standard of 18°C.
The trend of the curve for normal storage for indirect tensile strength, other things being equal, has a diminishing character than the 24-hour strength. This is contrary to the flexural strength development under similar storage conditions. However such reduction of strength does not raise alarm as there is appreciable strength reserve for design purposes. It is is also interesting to note that the mean Poisons' ratio falls in the range of 0.15.

3.3 Shrinkage

To assist, compare and contrast, Fig.4
is prepared based on total length. When
specimens are stored at low relative
humidity, 45%, the shrinkage time curve
is smooth and continuous up to 295 days;
similar shape as in Fig.1 for the same
storage regime. Strength reduction is
followed by shrinkage reduction as
indicated in Fig.4. Such behaviour affords
the following explanations:

Flexural Strength of H.A.C. Concrete
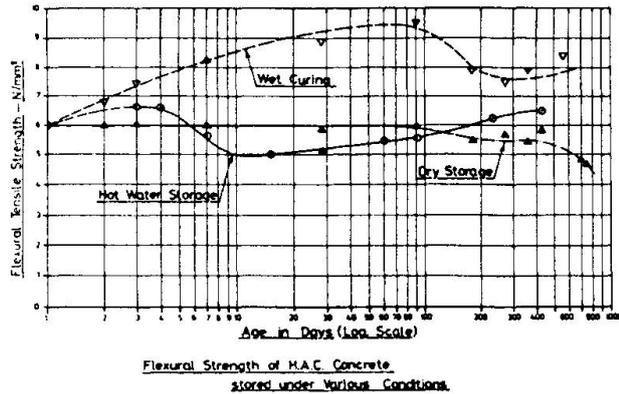stored under Various Conditions.

FIG. 3

1. In the absence of proper curing to achieve crystal maturity, the bond between paste matrix and gravel is weakened thereby partly relieving the restrain offered by gravel in the shrinkage mechanism.

2. The occurence of conversion, depending on exposure conditions, allows similar mechanism as that of item 1. It can safely be concluded that, unlike Portland cement concrete (PCC) where conversion prevails or proper curing is denied for crystals to mature, shrinkage is not only retarded by also reduced by some margin. The maximum shrinkage value obtained in this research project after 500 days storage was in the vicinity of 350×10^{-6}. If we assume 66 to 85% of the 20 year shrinkage occurs in one year, this will yield 413×10^{-6} in 20 year period comparable to PCC.

FIG.4

3.4 Swell

Consider for instance specimens stored
in hot water tanks (Fig.4). The diminution
of strength (Fig.1) is met to some extent
by corresponding increase in swelling. As
the strength recovery gradually takes
charge swelling starts to retard. Second
cycle of conversion will induce correspon-
ding increase in swelling until the reaction
ceases and the curve levels. The same
reasoning is afforded to normal curing
depending on rate of conversion. In general

Shrinkage - Time Relationship
for Samples stored under Various Conditions.
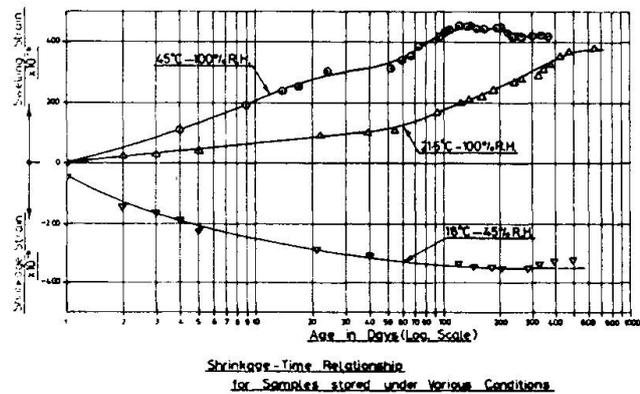
it can be concluded that while conversion reduces on one hand the net value of shrinkage, it promotes swelling on the other. The magnitude of swelling is irrespective of storage temperature and stands in the vicinity of 450×10^{-6}; greater than shrinkage value which runs contrary to L'Hermite's research data on PCC.

3.5 Creep

Unlike PC, the subject of creep in HAC is the most neglected area of research. A limited amount of research investigations(4) had been published. Glanville showed that the age of loading, other things being equal, has large effect on creep; slower start at earlier stage and an increasing trend at latter stage. This was also confirmed by the author for dry storage conditions.
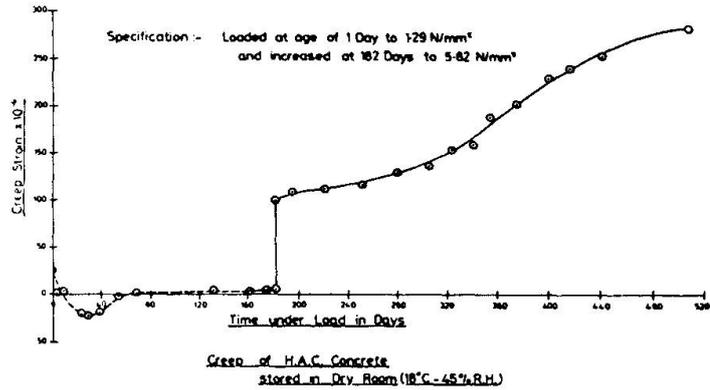
FIG. 5

3.5.1 Dry storage (Fig.5): The specimen was loaded to 13640N (1.29N/mm^2) until the age of 182 days. The curve in Fig.5 shows that creep becomes lower than the elastic deformation confirming Glanville's findings. At the age of 182 days, the sustained load was brought to 61340N (5.82 n/mm^2). The rate of creep progress is again sluggish up to 250 to 280 days and from there on creep increased at higher rate. After 400 days, creep deformation tends to achieve final value.
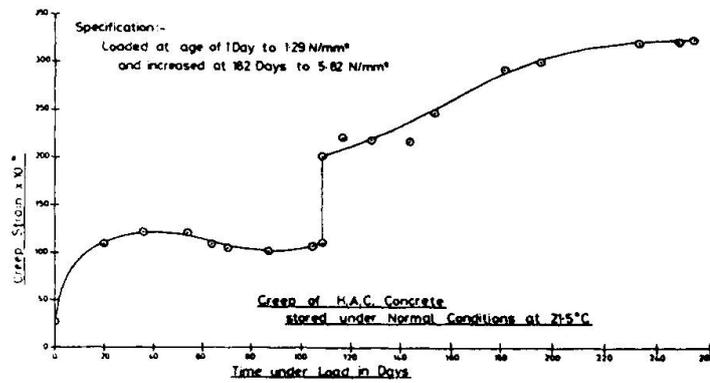
FIG. 6

3.5.2 Normal storage (Fig.6): specimens in this storage conditions were loaded to 13640N after one day cast and increased to 61340N at the age of 110 days. There appears a tendency for creep in dry storage to be less than in wet condition confirming Glanville's findings that the behaviour is organismically different from PCC. After 240 days, a slow increasing trend is observed.
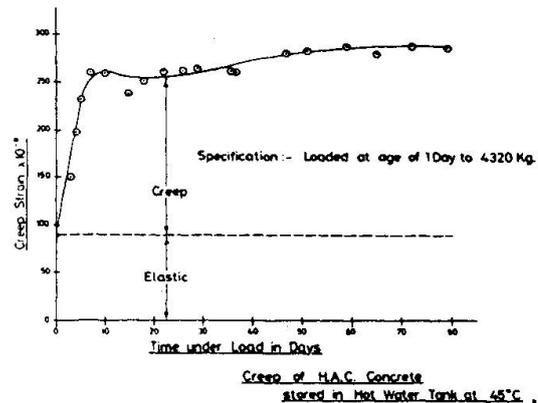
FIG. 7

3.5.3 Hot water storage (Fig.7): specimens were loaded to 43200N at the age of one day. The curve is more uniform than those discussed earlier admitting similarities to PCC creep behaviour.In other words full conversion from meta-stable compound (CA H10) to the stable compound (C_3AH_6) alters the behaviour in the creep-time curve. It follows that while porosity is a function of strength diminution, creep is dependent on the mineralogy or morphology of the hydrates formed. On the other hand at slow conversion HAC is organismically different from creep behaviour of PC while accelerated full conversion, before loading at best, offers similar behaviour as that of PC.

4   REFERENCES

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4. Glanville, A.M., Glanville, Etal, "Creep or flow of concrete underload", S.I.R., London, Building research Technical Papers Nos 12 and 21, 1930 and 39, pp 39 and 34.