Effect of age and specimen size on the transient thermal strain of concrete

G.A.Khoury, P.J.E.Sullivan, R.Gungoosingh & S.Malektojar
Imperial College, Civil Engineering Department, London, UK

1. INTRODUCTION

The authors have recently published extensive data on the transient thermal strain behaviour of several nuclear reactor pressure vessel type concretes during heating at an age of one year /1-6/. Concrete in nuclear reactors and other structures may, however, be subjected to an unscheduled thermal excursion, apart from heat of hydration, at ages ranging from several months to 30 years or more.

At ambient temperatures, the irrecoverable "flow" component of basic creep of concrete is known to reduce appreciably with age at loading, even after hydration and strength gain have ceased /7/. However, the effect of age upon the transient thermal strain behaviour of concrete is not known. Tests have, therefore, been performed to investigate the effect of age upon the free, and load induced, thermal strain of various concretes for temperatures up to 600°C. The ages at testing were 1 month, 2 months, 1 year and 9 years thus providing data for a wide age spectrum.

Another factor examined was the effect of specimen size upon the transient thermal strain of concrete. Various parameters such as temperature differentials /8/, stress distribution /3/ and moisture condition are influenced by specimen size. It is, therefore, important to ascertain the degree with which the transient thermal creep is sensitive to specimen size. This will help to determine whether the data obtained represent true "material" properties or are influenced by "structural" effects, and if so to what extent.

Cylindrical concrete specimens of two sizes were tested. The larger specimens have twice the linear dimensions of the smaller specimens, giving ratios of volumes and surface areas of 8.8 and 4.3 respectively.

2. COMPONENTS OF TRANSIENT THERMAL STRAIN

Thermal strains induced by first-time heating of concrete under load can be expressed in terms of (figure 1):

Free Thermal Strain (FTS)

Load-Induced Thermal Strain (LITS)

which have different and distinct properties. For example, FTS (which is the strain of concrete heated without load) is more sensitive than LITS to the type of aggregate used and the initial moisture content /1,4/.

The effects on LITS of the various material and environmental factors investigated previously can be summarized as follows:

LITS is not very sensitive to the initial moisture content (65-100% RH), cement blend or the type of aggregate used providing the aggregate itself does not disintegrate. A "master" LITS curve exists for C-S-H based concretes for temperatures up to at least 450°C, provided that the stress/initial-strength ratio (not stress level), preheating condition, heating rate and aggregate content by volume were similar. LITS is predominantly linearly related to stress in the load range from 10-30% of the initial strength. Only 5-20% more LITS occurred during "slow" heating at 0.2°C/minute compared with the five times faster heating rate of 1°C/minute /4/.

In this paper we shall examine the effects of two more factors, the age of the concrete and the size of the specimen.

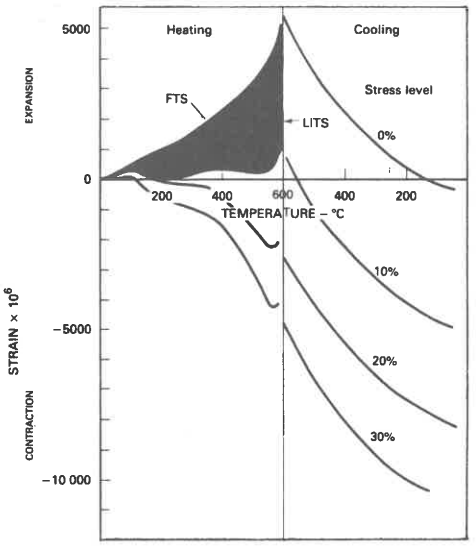

FIGURE 1:

Thermal strains of initially moist basalt aggregate concrete during first heating at 1°C/min under 4 load levels to 600°C and subsequent cooling /4/.

3. EFFECT OF AGE

The concrete mixes employed were identical to those published in reference 3. Concrete mix details are therefore not repeated here. All the specimens were heated at the same rate of 1°C/minute to 600°C under similar stress/initial-strength ratios (not similar stresses).

The transient thermal strains of lightweight concrete specimens tested at 1 month /9/ differed significantly from those of a similar concrete heated at an age of 1 year /1,4/. Although the FTS did not differ appreciably, the strains measured under load (and LITS) were greater at 1 month for temperatures up to about 150-200°C but were appreciably less at higher temperatures (figure 2). However, the thermal strains obtained for specimens heated at an age of 2 months /9/ were identical to those obtained at an age of 1 year /1,4/ for temperatures above about 200°C (figure 2).

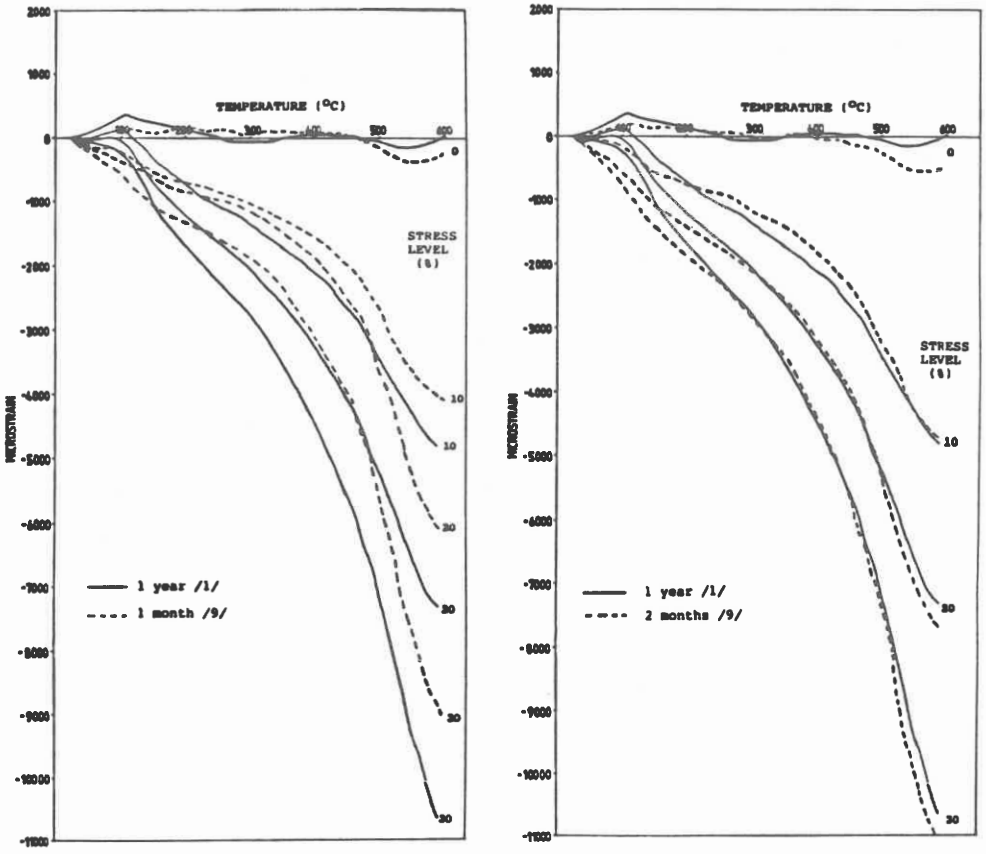

FIGURE 2:

Effect of age (1, 2 and 12 months) on the transient thermal strains during first heating at 1°C/min to 600°C of lightweight concrete under four load levels.

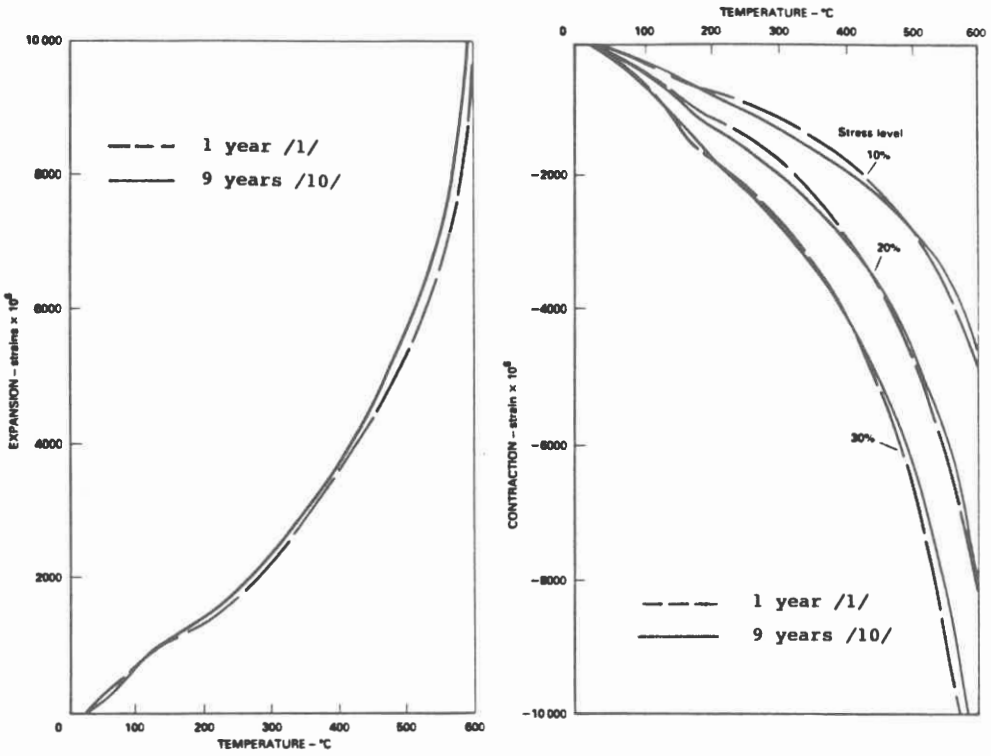

FIGURE 3:

Effect of age (1 and 9 years) on the (a) FTS of air-dried limestone concrete and (b) master LITS curves.

Although 9 year concrete consistently expanded more than 1 year concrete above 150°C (figure 3), the difference was not statistically significant. Nine-year old concrete, which was air-dried for 8 years, also expanded more above 250°C than initially moist concrete, which was maintained for 9 years at 100% R.H. /10/.

The effects of type of concrete, initial moisture content and stress level upon LITS were similar for 1 and 9 year old concretes. The LITS of 9 year limestone and basalt concretes also formed master curves up to 450°C /10/ which were not significantly different from those of 1 year old concrete /1,4/. However, limestone concrete tended to produce less LITS when heated at 9 years than at 1 year for temperatures above 450°C /10/.

The strains measured during cooling of the 9 year old limestone and basalt concretes /10/ were similar to those obtained from the 1 year old concretes /1,4/.

4. EFFECT OF SPECIMEN SIZE

The data published earlier /1,4/ were for cylindrical concrete specimens, 62 mm in diamter and 186 mm long. The

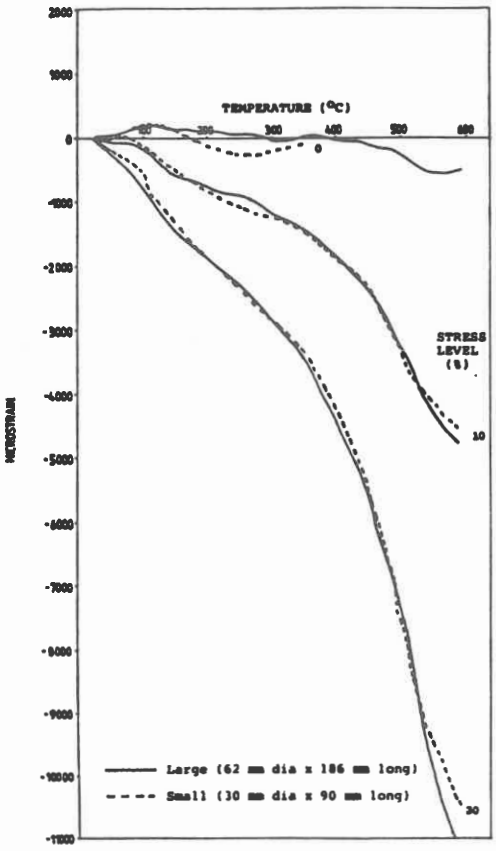

FIGURE 4:

Effect of specimen size on the transient thermal strains during first heating at 1°C/min to 600°C of lightweight concrete under three load levels /9/.

specimen diameter and heating rate were chosen to minimize temperature differentials during heating and hence "structural" effects. Identical tests have subsequently been performed /9/ on concrete specimens having about half the linear dimensions (30 mm dia x 90 mm long).

The transient thermal strains obtained from the two types of specimen were almost identical (figure 4) thus confirming that the tests performed using the larger specimens had produced real "material" properties not distorted by "structural" effects.

5. CONCLUSIONS

(a) Age Effect

The transient thermal strains of a given concrete heated for the first time under load to 600°C can be regarded, for practical purposes, to be independent of the age at heating for ages in excess of 2 months (1 year for temperatures up to about 200°C). The data published previously /1-6/ for 1

year concrete can, therefore, be employed in computer programs for the thermal stress analysis of concretes heated to 600°C at all ages in excess of about 2 months. It should be noted that, apart from heat of hydration, concrete structures, such as prestressed nuclear reactor pressure vessels, are unlikely to be exposed to very high temperatures at ages below about 2-12 months.

(b) Specimen Size Effect

The transient thermal strains obtained from the "large" and "small" specimens, everything else being equal, were identical although the ratios of volumes and surface areas were 8.8 and 4.3 respectively. This confirms that the data reported earlier /1-6/ for the larger specimens represented true material properties undistorted by "structural" effects. It can also be concluded that cylindrical specimens, 62 mm in diameter and 186 mm long, can be used to measure the transient thermal strains of concrete for heating rates up to about 1°C/min or possibly higher.

6. ACKNOWLEDGEMENTS

The authors thank Mr. Brian Grainger of the Central Electricity Research Laboratories for his interest an valuable help in this research programme.

7. REFERENCES

1. Khoury, G.A.
Transient thermal creep of nuclear reactor pressure vessel type concretes.
Ph.D. thesis submitted to the University of London, 1983.

2. Sullivan, P.J., Khoury, G.A. and Grainger, B.N.
Strain behaviour under uniaxial compression of three concretes during first heating to 600°C.
Transactions of the 6th Int. Conf. on "Structural Mechanics in Reactor Technology", Paper H1/3, Paris, 1981.

3. Khoury, G.A., Grainger, B.N. and Sullivan, P.J.E.
Transient thermal strain of concrete: literature review, conditions within specimen and behaviour of individual constituents.
Magazine of Concrete Research, Vol. 37, No. 132, pp. 131-144, September 1985.

4. Khoury, G.A., Grainger, B.N. and Sullivan, P.J.E.
Strain of concrete during first heating to 600°C under load.
Magazine of Concrete Research, Vol. 37, No. 133, pp. 195-215, December 1985.

5. Khoury, G.A., Grainger, B.N., Sullivan, P.J.E.
Strain of concrete during first cooling from 600°C under load.
Magazine of Concrete Research, Vol. 38, No. 134, pp. 3-12, March 1986.

6. Sullivan, P.J.E., Khoury, G.A. and Grainger, B.N.
Strain behaviour of three concretes during temperature cycling to 600°C.
Paper presented at the 8th Int. Conf. on "Structural Mechanics in Reactor Technology", Brussels, 1985.

7. Parrott, L.
An examination of the effects of age at loading upon the creep of hardened cement paste.
Magazine of Concrete Research, Vol. 25, No. 82, March 1973.

8. Khoury, G.A., Sullivan, P.J.E. and Grainger, B.N.
Radial temperature distributions within solid concrete cylinders under transient thermal states.
Magazine of Concrete Research, Vol. 36, No. 128, pp. 146-156, September 1984.

9. Gungoosingh, R.
The effect of age and specimen size on the transient strain of concrete.
M.Sc. Dissertation, Imperial College, June 1986.

10. Malektojar, S.
Creep of concrete at elevated temperatures.
M.Sc. Dissertation, Imperial College, June 1985.