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THERMAL STRESS-DEPENDENT DILATATION OF CONCRETE*

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Recent studies in nuclear fast reactor safety consider the possibility of concrete containment being subjected to extremely severe environmental conditions. Certain safety scenarios subject the concrete to very high temperatures hence raising the concern of containment integrity. Some of the main detrimental effects of high temperature on concrete are: reduction of strength, redistribution of moisture and etc. Consequently, analytical prediction of concrete response under the high temperature conditions becomes very complex.

A rather simple but important experiment of concrete at high temperatures was conducted by Anderberg and Thelandersson[1]. The test samples were small so that moisture was free to evaporate with no appreciable gradient as the temperature increased. Their results revealed that good correlation with analysis could be obtained if thermal expansion was made a function of both temperature and stress.

The method of relating the thermal strain to temperature and stress has been integrated into the TEMP-STRESS[2] code. Thus, high temperature concrete computational capability is now available for thermal-stress calculations.

An analytical illustration of the effect of high temperature is made for an axisymmetric cylinder, the test results of which have been described in Refs. 1 and 3. These test results pertain to a 75 mm diameter, 150 mm long cylindrical specimen, which is compressed axially at the ends and its external cylindrical surface is being heated by the temperature history given in Fig. 1. The concrete specimen stress-strain data, ranging from room temperature through 770°C, are displayed in Fig. 2.

The structural calculations were carried out for varying axial loads of 0.0%, 22.5%, 35%, 45% and 67.3% of f'_c, where f'_c is the compressive strength of the concrete at ambient temperature. The thermal strain was taken as

$$\varepsilon_{TH} = \alpha \, \Delta T,$$

and

$$\alpha = \alpha_1 - \alpha_2 \left(\frac{\sigma}{f'_c}\right),$$

where ε_{TH} is the thermal strain, ΔT is the temperature change, α_1 is the conventional coefficient of thermal expansion, α_2 is the stress-dependent thermal strain coefficient of expansion and σ is the stress. Analytical results are computed for the values of $\alpha_1 = 9.2 \times 10^{-6}/°C$ and $f'_c = 43$ MPa; $\alpha_2 = 0$ in Fig. 3a and $\alpha_2 = 2.35$ in Fig. 3b.

The results of Fig. 3 indicate that for the conventional thermal stress calculations ($\alpha_2 = 0$), the experimental results can not be matched, except for the case of zero axial load. For the value of $\alpha_2 = 2.35$ the experimental results can be predicted quite well for all load levels. It is seen that thermal strain based on temperature and stress are important in the response of this experiment.

The response of concrete which is subjected to high temperature can be modeled successfully if an additional thermal strain (proportional to stress) is added. This approach is convenient to model concrete behavior at high temperatures, where moisture effects need not be taken into account.

Reference

1. Anderberg, Y. and Thelandersson S., "Stress and Deformation Characteristics of Concrete at High Temperatures," Bulletin 54, Land Institute of Technology, Sweden, 1976.

2. A. H. Marchertas and R. F. Kulak, "A Coupled Heat Condition and Thermal Stress Formulation Using Explicit Integration," ANL-82-47, June 1982.

3. Thelandersson, S., "On the Multiaxial Behavior of Concrete Exposed to High Temperatures," Trans. of the 7th Int. Conf. on SMiRT, Vol. H, Paper H 3/1, Aug. 1983, pp. 119-126.

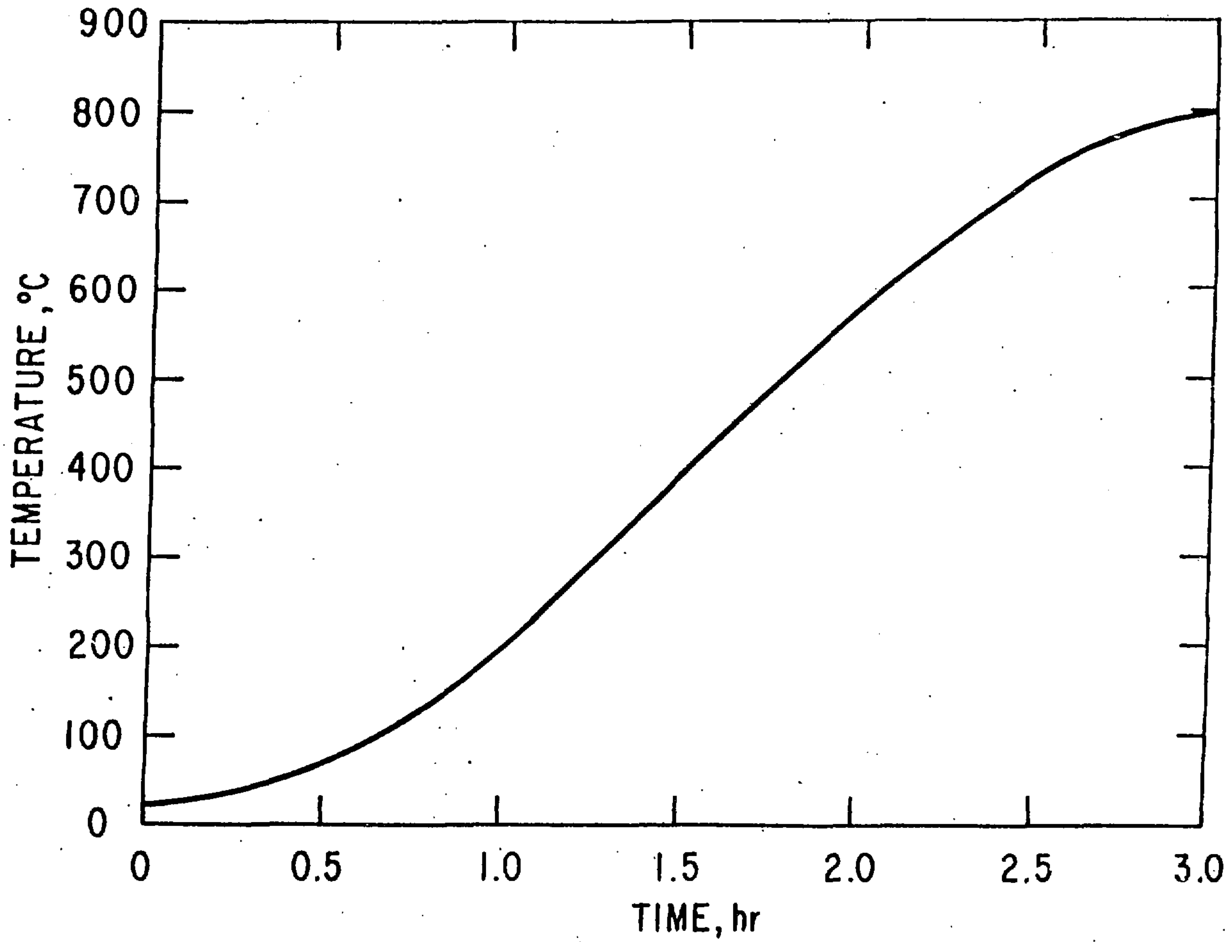

Fig. 1. Temperature History of the Specimen Surface

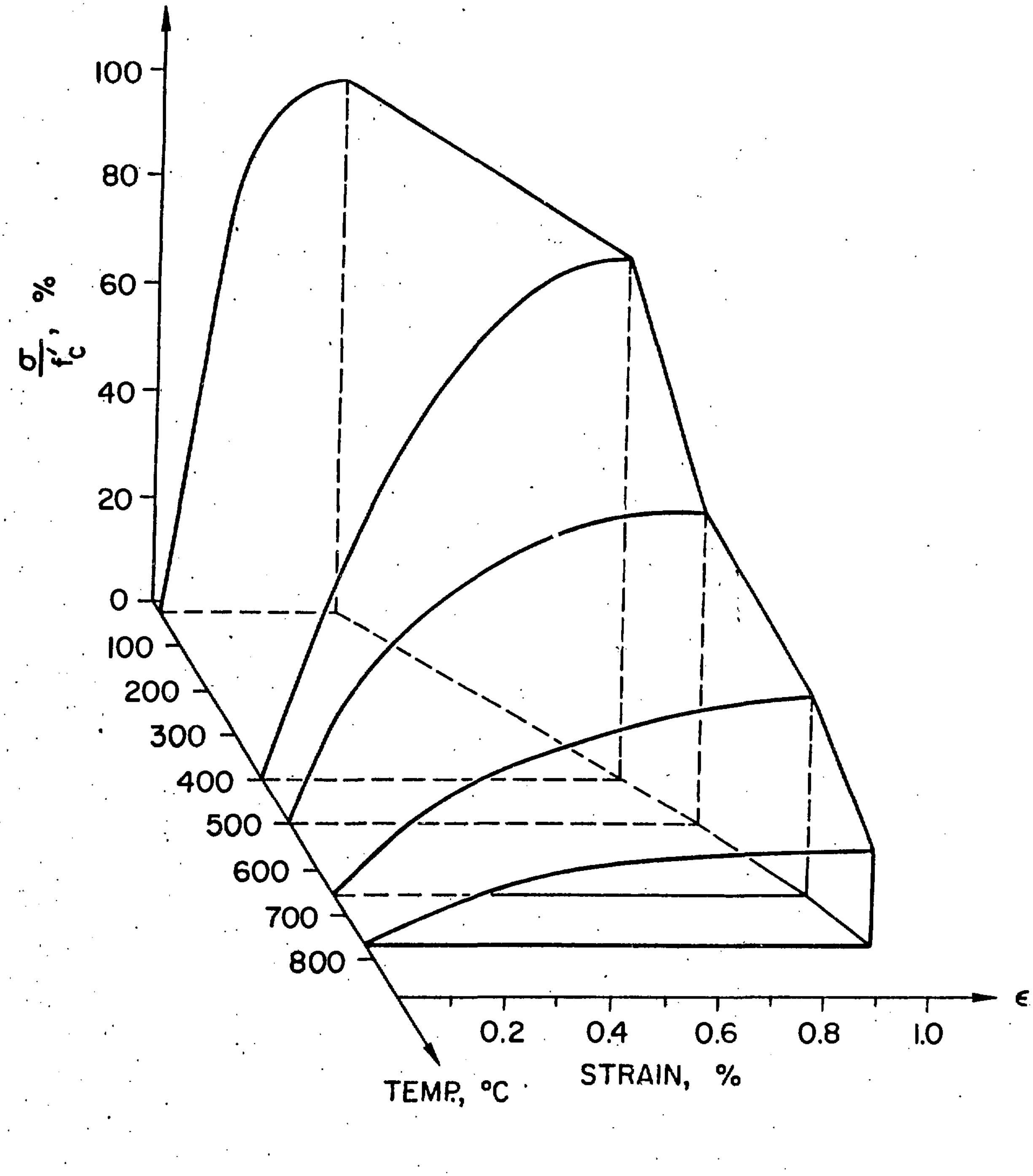

Fig. 2. Stress-Strain Behavior of Concrete at High Temperatures

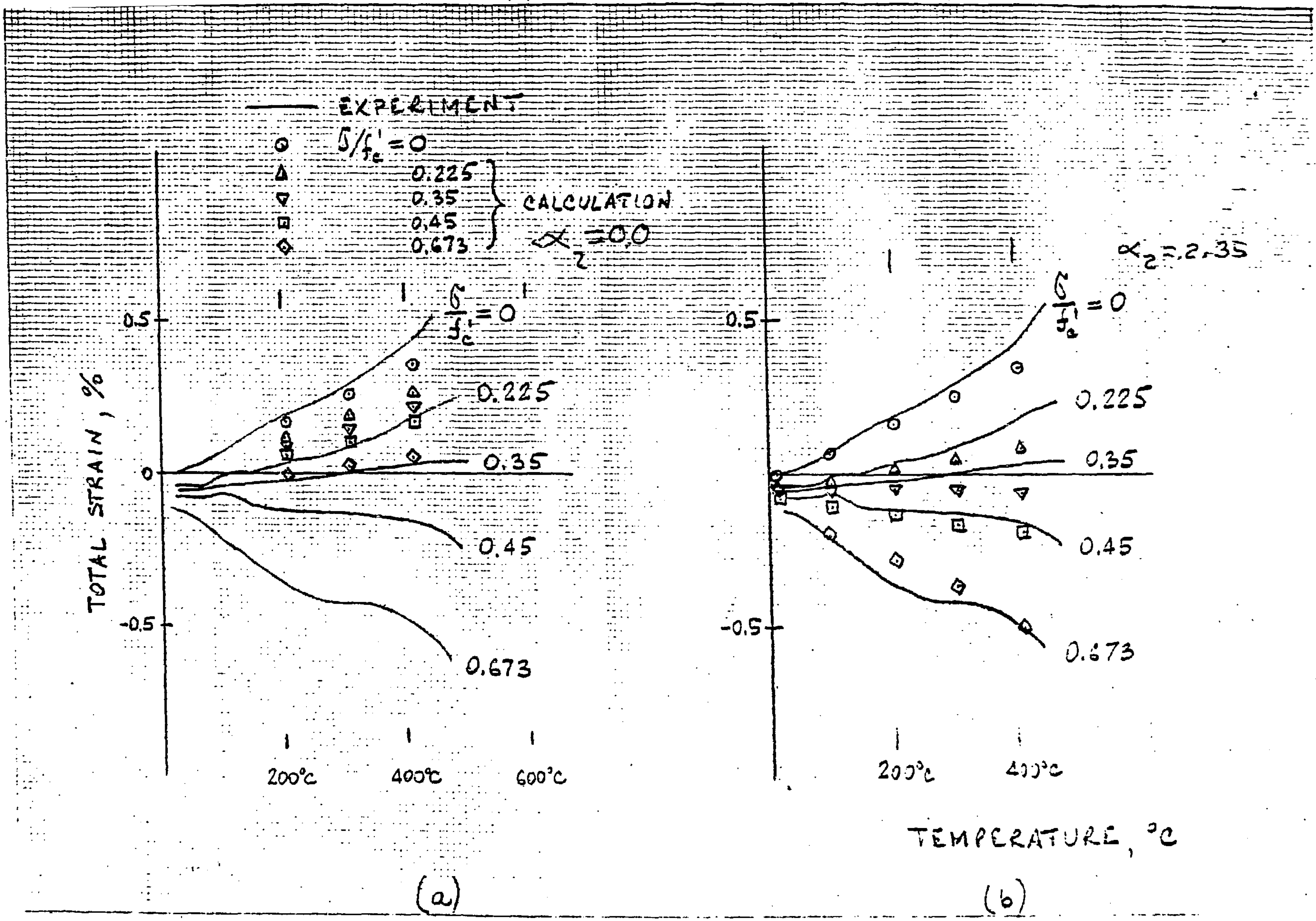

Fig. 3. Deformation at Different Levels of Compressive Stress