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CREEP AND CYCLING TESTS - THERMAL
PROPERTIES OF HANFORD CONCRETES

by

Michael Gillen

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S Y N O P S I S

Four tests were conducted to determine thermal properties of concrete core material from the Purex Building at Hanford, Washington, and from concrete cast at the Portland Cement Association. Specific heat, thermal conductivity, and thermal diffusivity were measured as functions of temperature from 79 to 1175F.

Testing was conducted by personnel of the Research Section, Division of Building Research, of the National Research Council in Ottawa, Canada.

INTRODUCTION

This report describes a portion of an ongoing program undertaken to determine the thermal and mechanical properties of Hanford concrete at elevated temperatures. Data are reported from tests to determine specific heat, thermal conductivity, and thermal diffusivity. Specimens were concrete core material from the 202-A Purex Canyon Building at Hanford, Washington or from concrete cylinders cast at the Portland Cement Association (PCA) laboratories. Portland Cement Association specimens were cast using materials and mix designs similar to those used in Hanford concrete structures.

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TEST MATERIALS

Two test specimens were obtained from concrete cored from the 202-A Purex Canyon Building at Hanford, Washington. Thermal test specimens were cut from cores identified as SA-8E-3 and SA-12W-3.

Two additional specimens were obtained from 6x12-in. cylinders cast at the Construction Technology Laboratories of the Portland Cement Association. Cylinders were cast in September 1977, with materials and mix designs similar to those used in construction of Hanford concrete structures. Specimens obtained from these cylinders were identified as 3K14-20 and 4.5K12-4.

All test specimens were dried at 105C to constant weight prior to testing.

TEST METHODS

Test methods used permitted the determination of specific heat, thermal conductivity, and thermal diffusivity using pulsed or rapid application of heat to the specimen. By monitoring temperature response at various specimen locations and by assuming linear heat flow in a localized area, thermal properties were determined using curve-fitting techniques.

These methods are suited for measurement of thermal properties of materials such as concrete, that undergo rapid physico-chemical changes on heating. These variable-state methods were developed at the Fire Section, Division of Building Research of the Canadian National Research Council.

A detailed description of the test methods may be found in a paper by Harmathy^{(1)*}. A copy of this paper has been included in the Appendix.

TEST RESULTS

Results of tests on each of the four specimens are listed in Table 1. Thermal property measurements are described.

Thermal Diffusivity

Thermal diffusivity, κ , measures the rate at which temperature changes may take place within a material. Diffusivity is related to specific heat, c , and thermal conductivity, k , by the following equation:

$$\kappa = \frac{k}{c\rho}$$

where ρ is the material density.

Neville states that typical values for diffusivity of normal-weight concrete range from 0.02 to 0.06 ft²/hr, depending upon the type of aggregate incorporated into the concrete⁽²⁾. He further states that basalt rock aggregates, of the type used in Hanford concretes, produce lower than average values for concrete diffusivity than concrete incorporating other normal-weight mineral aggregates.

Examination of Figs. 1 - 4 shows this to be true. Diffusivity of Hanford concrete cast at the Portland Cement

*Superscript numbers in parentheses refer to References on Page 22

TABLE 1 THERMAL CONDUCTIVITY TESTS OF HANFORD AND PUREX CONCRETE

Specimen Number	Temperature, F	Density, Lb/Cu Ft	Thermal Diffusivity, Ft ² /Hr	Thermal Conductivity, Btu/Ft/Hr/F	Specific Heat, Btu/Lb/F
4.5K 12-4 (Hanford)	79	139.8	0.0240	0.8138	0.2419
	320		0.0218	0.8283	0.2715
	590		0.0184	0.7456	0.2904
	887		0.0176	0.6913	0.2811
	1175		0.0147	0.6092	0.2957
	968		0.0157	0.6005	0.2737
	869		0.0159	0.6086	0.2739
	626		0.0147	0.5387	0.2614
	356		0.0154	0.5208	0.2422
	79		0.0171	0.4965	0.2154
3K 14-20 (Hanford)	79	141.0	0.0322	0.9549	0.2105
	320		0.0252	0.8861	0.2486
	626		0.0220	0.7138	0.2297
	1166		0.0174	0.6514	0.2654
	1040		0.0165	0.5959	0.2564
	752		0.0181	0.6133	0.2404
	383		0.0185	0.5595	0.2138
	79		0.0246	0.5977	0.1779

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TABLE 1 THERMAL CONDUCTIVITY TESTS OF HANFORD AND PUREX CONCRETE (Con'td.)

Specimen Number	Temperature, F	Density, Lb/Cu Ft	Thermal Diffusivity, Ft ² /Hr	Thermal Conductivity, Btu/Ft/Hr/F	Specific Heat, Btu/Lb/F
SA-8E-3 (Purex Bldg.)	79	146.0	0.0197	0.5820	0.2024
	302		0.0186	0.6543	0.2410
	545		0.0195	0.7843	0.2746
	941		0.0177	0.7196	0.2783
	1166		0.0174	0.7676	0.3024
	968		0.0169	0.6861	0.2776
	869		0.0169	0.6537	0.2650
	581		0.0165	0.5578	0.2314
	374		0.0178	0.6092	0.2342
SA-12W-3 (Purex Bldg.)	79	144.1	0.0213	0.6560	0.2136
	302		0.0185	0.7456	0.2793
	590		0.0160	0.6445	0.2781
	950		0.0150	0.5803	0.2788
	1166		0.0143	0.6144	0.2982
	977		0.0146	0.6156	0.2918
	851		0.0148	0.5728	0.2678
	626		0.0157	0.5722	0.2531
	374		0.0155	0.5260	0.2342

RHO-C-27

FIG. 1 THERMAL DIFFUSIVITY OF HANFORD CONCRETE

FIG. 2 THERMAL DIFFUSIVITY OF HANFORD CONCRETE

FIG. 3 THERMAL DIFFUSIVITY OF PUREX BUILDING CONCRETE

FIG. 4 THERMAL DIFFUSIVITY OF PUREX BUILDING CONCRETE

Association, Figs. 1 and 2, varied from a maximum of 0.0322 ft²/hr at room temperature to a minimum of about 0.015 ft²/hr at 1175F.

Concrete cored from the Purex Building showed less variation in magnitude of thermal diffusivity with changes in temperature. Highest value, 0.0213 ft²/hr, was measured with specimen SA-12W-3 at room temperature; while the lowest value, 0.0143 ft²/hr, was measured with the same specimen at 1166F. Thermal diffusivity of Purex Building specimens are plotted as a function of temperature in Figs. 3 and 4.

Thermal Conductivity

Thermal conductivity, k, is a measure of the rate at which heat will flow down a temperature gradient in a material. For concrete, thermal conductivity is strongly dependent on aggregate mineral composition. As with diffusivity, thermal conductivity of concrete made with basalt aggregate tends to have lower values than concrete fabricated from most other natural mineral aggregates⁽²⁾.

The presence of moisture inside concrete also has a major influence on measured values of thermal conductivity. Lower moisture content reduces conductivity in concrete because air has a lower thermal conductivity than water. However, moisture content of concrete can vary greatly, making it difficult to state a "typical" value for concrete thermal conductivity. Neville quotes a representative value for concrete with a density of 140 lb/cu ft of about 1.1 Btu/ft/hr/F⁽²⁾.

Examination of Figs 5 - 8 shows that Hanford concretes do exhibit smaller values for thermal conductivity than the stated typical value. Samples from concrete cast at PCA had room temperature values of approximately 0.81 and 0.95 Btu/ft-hr-F. Samples from the Purex Building had ambient temperature values of about 0.58 and 0.66 Btu/ft-hr-F.

Heating specimens of concrete cast at PCA tended to reduce thermal conductivity below ambient temperature values. Thermal conductivity of Purex Building specimens varied in a more complex manner when heated. Initial heating produced an increase in thermal conductivity of both Purex specimens. Further heating produced a decline, followed by a second increase in thermal conductivity values at temperatures above 900F.

Specific Heat

Specific heat, c , is a measure of the heat capacity of a material. For concrete, c , is reported to be little influenced by the mineralogy of the aggregates, but does increase with increased free moisture within the concrete mass. Typical values for concrete made with normal-weight aggregates range from 0.2 to 0.28 Btu/lb-F^(2,3).

In Figs. 9 - 12, it can be seen that specific heat of Hanford concretes had room temperature values near the lower limit of the stated range. Heating specimens produced an increase in values of specific heat. Near maximum test temperature three specimens had values of $c \sim 0.30$ Btu/lb-F.

FIG. 5 THERMAL CONDUCTIVITY OF HANFORD CONCRETE

FIG. 6 THERMAL CONDUCTIVITY OF HANFORD CONCRETE

FIG. 7 THERMAL CONDUCTIVITY OF PUREX BUILDING CONCRETE

FIG. 8 THERMAL CONDUCTIVITY OF PUREX BUILDING CONCRETE

FIG. 9 SPECIFIC HEAT OF HANFORD CONCRETE

FIG. 10 SPECIFIC HEAT OF HANFORD CONCRETE

FIG. 11 SPECIFIC HEAT OF PUREX BUILDING CONCRETE

FIG. 12 SPECIFIC HEAT OF PUREX BUILDING CONCRETE

SUMMARY

In this study specific heat, thermal conductivity, and thermal diffusivity of four Hanford concrete specimens were measured at temperatures from ambient to 1175F. Two specimens were fabricated from concrete cast at the Portland Cement Association using materials and mix designs similar to those used in Hanford concrete structures. Concrete cores from the Purex Building in Hanford, Washington, provided material for two additional specimens.

Thermal properties tests were conducted by personnel of the Fire Section, Division of Building Research, of the National Research Council of Canada. Test methods and equipment used were developed at the Laboratory of the Fire Section.

Results of tests may be summarized as follows:

1. Specific heat, thermal conductivity, and thermal diffusivity of Hanford concretes near ambient temperature were lower than most values reported for normal-weight (p~140 lb/cu ft) concrete in the literature. Thermal properties of basalt are also low. Aggregates used in Hanford concretes are primarily basalt, and may be responsible for the low-measured values of thermal properties.
2. Heating caused reductions in values of thermal conductivity and diffusivity of most Hanford

concrete specimens. However, specific heat of most specimens at elevated temperatures were somewhat higher than their ambient temperature values.

3. Cooling caused reductions in all thermal properties of most test specimens from their values at maximum test temperatures. Thermal conductivity values were most affected by cooling. In contrast, specific heat values were the least affected.

REFERENCES

1. Harmathy, T. Z., "Variable-State Methods of Measuring the Thermal Properties of Solids," Journal of Applied Physics, Vol. 35, No. 4, April, 1964.
2. Neville, A. M., Properties of Concrete, John Wiley and Sons, 1973.
3. Harmathy, T. Z., "Thermal Properties of Concrete at Elevated Temperatures," Journal of Materials, Vol. 5, No. 1, March, 1970, pp 47-74.

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