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PROPERTIES OF CONCRETE AT ELEVATED TEMPERATURE

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PROPERTIES OF CONCRETE AT ELEVATED TEMPERATURES

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INTRODUCTION

The physical (thermal) and mechanical (strength) properties of concrete at elevated temperatures have become a topic of increased interest in the structural design and analysis of advanced energy system facilities. These materials properties are currently under investigation for limestone aggregate concrete in a comprehensive testing program conducted at Oak Ridge National Laboratory as a part of an ongoing investigation by Burns and Roe, Inc. for the Clinch River Breeder Reactor Plant Project (CRBRP). These materials properties are being investigated by Burns and Roe, Inc. to provide the basis for the design and evaluation of CRBRP structures under accident temperatures resulting from postulated large molten sodium spills in steel lined cells.

This paper describes the ongoing testing program developed to determine the variations in the physical (thermal) and mechanical (strength) properties of limestone aggregate structural concrete, and the physical (thermal) properties of perlite insulating concrete exposed to sustained elevated temperatures up to 621°C (1150°F). The testing program developed by Burns and Roe, Inc. and Oak Ridge National Laboratory is formulated to identify the behavioral trends from the effects of elevated temperature on the mechanical properties of unconfined compressive strength, shear strength, reinforcing bar bond strength, sustained loading (creep) behavior, and the physical properties of thermal expansion, conductivity and diffusivity.

Included in this paper as references are the published results of an extensive literature study of data on the elevated temperature response of structural concrete including proposed design relationships, confirmatory testing results, and discussion of how the test results are intended to be considered in the structuraal design.

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REVIEW OF PUBLISHED RESULTS

An extensive literature study summarizing the results of compressive strength and modulus of elasticity testing of structural concrete at elevated temperatures was performed by Burns and Roe, Inc. and presented in Ref. (1). The results of this literature study were used to determine the factors governing the elevated temperature strength and elasticity properties of structural concrete, to establish reliable and representative design relationships, and to determine the bounding case exposure conditions of concrete at elevated temperatures for incorporation into an interim testing program spanning the temperature range of ambient to 760°C (1400°F). As reported in Refs. (1 and 2) the interim testing program performed at ORNL confirmed the relationships established by the literature study. As described in Ref. (2) the interim testing program consisted of uniaxial compression tests performed on twenty-four standard 15.2 cm ⌀ x 30.5 cm (6" ⌀ x 12") limestone aggregate structural concrete cylinders having a design strength of 27.58 MPa (4,000 psi). The specimens were exposed to the prescribed elevated temperature for 14 days after a heatup at 17°C/hr (30°F/hr). They varied in age from 263 to 587 days. By utilizing the compressive strength of control cylinders from the same batches as the test cylinders the effect of age was isolated from the determination of the residual compressive strength and residual modulus of elasticity.

The tests were performed under two lower bound testing conditions (Ref. 1). These conditions were:

Open-Hot Testing

Testing performed in an open moisture migration environment which allows for the free loss of moisture during heating. The specimens were tested while hot after a 14 day period of temperature stabilization. This exposure condition simulates the response of a concrete element which is either vented or has free atmospheric communication during a thermal accident.

Closed-Cold Testing

Testing performed in a closed moisture migration environment which prevents the release of moisture during heating. The specimens are tested following a cooldown to ambient temperatures after a 14 day period of stabilization at an elevated test temperature. This exposure condition simulates the response of a concrete element located within an unvented region or within a massive concrete structure.

Reference (1) summarizies the results of the interim program and presents a method for the use of the data in design evaluation.

SCOPE OF THE COMPREHENSIVE TESTING PROGRAM

The results of the interim testing program, while confirming the design relationships developed in Ref. (1) did not sufficiently define all the physical (thermal) and mechanical (strength) properties of structural concrete required for the structural design and thermal accident analyses. Accordingly a more comprehensive program was developed. This ongoing testing program contains the following:

1. Elevated Temperature Uniaxial Compressive Strength Tests

A series of 30 residual compressive strength tests are being performed on standard cylinders of 60 day old limestone aggregate concrete having a design strength of f'_c = 31.72 MPa (4600 psi) minimum. Twenty-one of the tests are being performed with three specimens each tested at seven test temperatures between 66°C (150°F) and 621°C (1150°F) after being maintained at the test temperature 14 days. The other 9 tests are being performed at three temperature levels between 66°C (150°F) and 177°C (350°F) after thermal stabilization for 28 days. The purpose for the increased time at test temperature is to determine the effects, if any, of increased exposure durations. All concrete test specimens are heated to their test temperature at a rate of 17°C/hr. (30°F/hr) and tested in the open-hot testing condition (Ref. 2). The results of these tests will provide additional data on the properties of: Residual Strength % f'_c, Residual Elasticity %E, Stress-Strain Relationships and Poissons Ratio and their variation with elevated temperature exposure. Also, a series of 18 residual compressive strength tests are being performed on standard cylinders of 60 day old perlite insulating concrete having a design strength of f'_c = 6.21 MPa (900 psi) minimum. This material, which is used as insulation behind the cell liners in the Clinch River Breeder Reactor Plant, is being tested for mechanical properties in the same manner as the structural concrete.

2. Elevated Temperature Shear Strength Tests

A series of 24 residual shear strength tests are being performed on s-shaped parallelepipeds of limestone aggregate structural concrete with precast trapezoidal-shaped notches. Three specimens each are being tested under the open-hot moisture migration conditions following a 14 day heat stabilization period at eight temperature levels between ambient and 620°C (1150°F). The specimen geometry provides a shear plane which is loaded similarly to the uniaxial tests. Reinforcing steel is needed to resist bending moments in the upper and lower cantilever portions of the specimens. A uniaxial load is applied across the shear section at a rate of 6670 N/s (1500 lb/sec.) or less until the specimen fails across the shear plane. The maximum load (Vu) is recorded, and the residual shear strength determined with respect to time and temperature.

3. Elevated Temperature Bond Strength Tests

A series of 24 residual bond strength tests are being performed on 30.5 cm. (12 in) cubes of limestone aggregate structural concrete with an ASTM A 615, Grade 60, Number 11 rebar positioned vertically through the center of the specimen. Three specimens are being tested at each of eight temperatures between ambient and 621°C (1150°F) after a 14 day heat stabilization period. The rebar extends beyond the surface of the concrete specimen and into a hydraulic actuator and load cell assembly connected to a reaction frame. The specimen is heated on four sides to the specified test temperature at the common test rate of 17°C/hr. (30°F/hr). The tensile load applied on the rebar results in a relative rebar movement of 1.27 mm/ min. (0.05 in/min). The movement of the rebar and the applied load are monitored and the bond stress at elevated temperatures is determined.

4. Sustained Load (Creep) Tests

A series of 15 sustained load (creep) tests are being performed at a total of four temperature levels between 66°C (150°F) and 538°C (1000°F). The tests are being performed on standard size limestone aggregate concrete cylinders under dead weight constant loading of up to 50% of the ultimate capacity of the concrete. Specimens are instrumented to monitor load, deformation and test temperature over the two-month duration of the creep tests.

5. Physical Parameters Testing

Both the limestone structural aggregate concrete and the perlite insulating concrete are being tested at the University of California to determine the variation in thermal conductivity, diffusivity, thermal expansion & specific heat with respect to elevated temperatures to 621°C (1150°F).

CONCLUSIONS

The Comprehensive Testing Program results are not available, but initial data confirms the Ref. (1) results.

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