The Effect of High Temperatures on the Effective Thermal Conductivity of Concrete

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Introduction

Concrete thermal conductivity is an important property for thermal analysis of nuclear accidents. Concrete compositions include water, sand, cement and aggregates of various kinds and combinations. Values of concrete's thermal conductivity for some different compositions can be found in the literature[1] but since the material composition and its temperature significantly affect this property, the exact value of a specific composition should be measured.

Experimental Setup

In order to enable the measurement of concrete's thermal conductivity, a cylindrical apparatus has been designed and used, as presented in Fig. 1. The system consists of a P.V.C tube with an inside diameter of 45 mm and length of 290 mm. Those dimensions were chosen in order to avoid end effects. An electrical heat wire is placed at the center of the P.V.C tube and used as heat source. Both ends of the heat wire are connected to the copper electrodes of the power source. A wooden plate is used as the base of the P.V.C tube. In order to measure the temperatures at accurate radial locations, 8 thermocouples are placed in a wooden rod with 8 holes passes through the centerline of the P.V.C tube. The concrete mixture is prepared out of the system and cast into the P.V.C tube. All measurements were taken after 28 days, when the concrete gets its final properties [2].

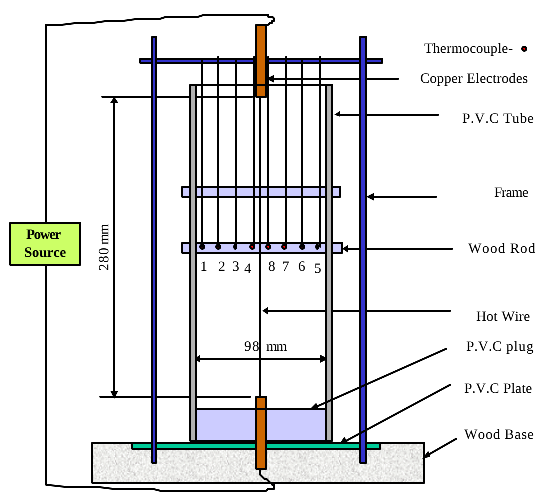

Fig 1: Schematic diagram of the experimental apparatus

Under steady state conditions, ignoring end effects, the heat flow outwards through a cylindrical surface of radius r and length L is:

$$q = -2p\ rLk\,\frac{dT}{dr} \qquad (1)$$

Where T is the temperature at a radial location r and k is the thermal conductivity. The mean effective thermal conductivity, $k_{eff,}$ is obtained by integration, between two radial locations. Subscripts "i" and "o" describe the inner and outer radii in which the temperatures are T_i and T_0, respectively.

$$k = \frac{q\ln(r_0/r_i)}{2p\ L(T_i - T_0)} \qquad (2)$$

In order to overcome the error caused by the displacement of thermocouples from their exact location, equation 1 can be written as:

$$T(r) = T(R) + \frac{q_L}{2pk}\ln(R) - \frac{q_L}{2pk}\ln(r) \equiv A + B\ln(r) \qquad (3)$$

Where q_L is the heat flow supplied by the heat wire, $T(R)$ the temperature measured at radius R and $T(r)$ the temperature calculate at radius r.

The thermal conductivity (k) can be calculated from the slope of the temperature versus ln(r) curve:

$$k = \frac{q_L}{2pB} \qquad (4)$$

Results and Discussion

The thermal conductivity of concrete at elevated temperatures has been measured. Two kinds of concrete has been examined, one without aggregates (mortar) that includes cement, sand and water in a ratio of 1:4:2, and the other with aggregates (B-300) includes cement, sand, water and aggregates in a ratio of 1:2:1:1 respectively.

The experimental procedure consist of two major steps: 1: heating 2:cooling. The heating procedure conducted by raising the power supply to the system step by step. At each step temperatures at the 8 thermocouples were recorded after the system reached steady state. Cooling was conducted by reducing the power supply until the system reached the ambient temperature.

Fig. 2 presents the results of mortar. Each point at the red and blue curves is an average value of thermal conductivity calculated from thermocouples 1÷4 (left side) and 5÷8 (right side), respectively. The black curve shows the average value of thermal conductivity calculated from all 8 thermocouples. From this figure it can be seen that the system is symmetric and that the average value represents the whole system.

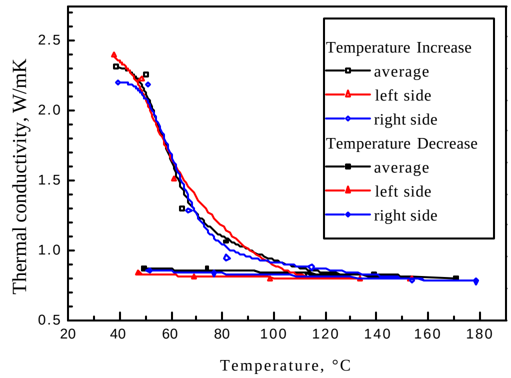

Fig 2: Thermal conductivity of mortar versus average temperature

The results of concrete B-300 with aggregates is shown in Fig 3.

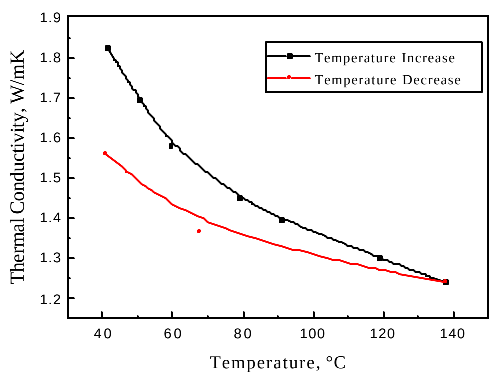

Fig 3: Thermal conductivity of concrete B-300 versus average temperature

In general, both experiments shows that the concrete and mortar thermal conductivity decreases significantly as the temperature increases. When the system cools down and its temperature decreases, the concrete thermal conductivity increases. However, a hysteresis is clearly found. The meaning of this phenomena is that in order to predict the thermal conductivity of a concrete, a knowledge of its temperature is not enough and the temperature history should also be defined.

References

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