## SOME THERMAL PROPERTIES OF CONCRETE.

By Charles L. Norton, Mem.Am.Soc.M.E.

A few of the results of a series of experiments carried on at the Massachusetts Institute of Technology, during the past four-and-a-half years, formed the subject of a paper read by Prof. Norton, at a meeting of the American Society of Mechanical Engineers, in Boston, on February 25th. The purpose of the research was a study of the physical properties of Portland cement concrete, which affect its value as a fire resistant material. The experiments had not been completed, but there was much of interest in what had been already ascertained.

It was proposed at the outset to make a study of the various physical properties of Portland cement concrete over as wide a range of temperatures as possible, and among the properties were the following:—

a Coefficient of linear expansion
b Diminution of mechanical strength after heating
c Specific heat.
d Coefficient of thermal conductivity

A comparison with other materials was also planned.

**Coefficient of Linear Expansion**—The measurements of the coefficient of linear expansion are now practically completed. The method adopted for the measurements of elongation caused by heating was the common so-called telescope method. The specimens in the shape of 6-in. or 10-in. cubes were slowly heated in a double gas muffle or an electric resistance furnace. The temperature of the furnace and of a number of points in the concrete was taken by means of platinum-rhodium couples. Near the furnace were mounted two telescopes, which could be sighted through holes in the furnace wall upon reference points on the surface of the block. At low temperatures an arc light and system of mirrors were used to furnish adequate illumination. One of the telescopes was provided with a micrometer eye-piece by means of which a movement of the reference mark of 0.0001 in. could be measured.

The values obtained at low temperatures agree very well with the commonly accepted value of 0.0000055 for the elongation per unit of length per deg. Fahr. Apparently, this value increases slightly up to 575 deg. Fahr. Above this point the coefficient becomes smaller; at 1,500 deg. Fahr. the coefficient becomes zero, and above this point, slightly negative.

Table 1 gives the average values for a large number of specimens:—

**Table 1 Average Value of Specimens.**

| Temperature, Deg. Fahr. | in the Expression $l_t = l_0 (1 + \beta t)$ |
|---|---|
| 72 to 360 | 0.0000045 to 0.000060 |
| 72 to 750 | 0.0000050 to 0.000060 |
| 72 to 1090 | 0.0000045 to 0.000050 |
| 72 to 1600 | 0.0000035 to 0.000042 |

The blocks which have been heated to 1,500 deg., did not return to their original dimension on cooling, their permanent elongation being about 75 per cent. of their maximum elongation. There was no sensible permanent elongation resulting from a second heating.

All of the specimens tested for expansion were of stone concrete of the proportions 1: 2: 5. The stone was clean, the sand sharp, the cement of good quality, and every precaution was taken to secure a concrete of the first order. The specimens weighed on the average 150 lb. per cu. ft. A considerable number of tests demonstrated that the dimension which these small cubes took during a rise in temperature was dependent upon the temperature of the outside rather than the average temperature of the block.

The variation of this coefficient with the temperature is such as to make the difference between it and the coefficient for steel considerable at high temperatures. As has been well understood, the similarity of the coefficient is helpful in preserving the integrity of reinforced concrete structures at ordinary temperatures, but the divergence of the two coefficients at higher temperatures is not a serious matter in the reinforced structure when exposed to fire, since the metal reinforcement and the concrete surface are rarely at the same temperature.

There is a marked expansion increase up to about 700 deg. Fahr., followed by a slower rate, and at about 1,500 deg. Fahr. by marked shrinkage.

**Comparison with Clay Brick and Silica Brick.**

| Temperature Range, Deg. Fahr. | Clay Brick | Silica Brick |
|---|---|---|
| | Coefficient of Expansion ($\beta$) | |
| 0 to 900 | 0.0000038 | 0.000012 |
| 0 to 1600 | 0.0000031 | 0.000008 |
| 0 to 1900 | 0.0000023 | 0.000007 |

Some bricks and all concrete are liable to a permanent set of about 75 per cent. of their total elongation on heating to 1,500 deg. Fahr.

**Diminution of Mechanical Strength after Heating**—In order to study the effect of high temperatures upon the compressive strength of concrete several scores of 6-in. and 8-in. cubes were made and allowed to set for 90 days or slightly longer. These blocks were heated at different temperatures in a gas furnace similar to that used for the expansion experiments, for different lengths of time at various periods from the 90 days up to five years.

The cubes which were not heated showed an average compressive strength of 2,700 lb. per sq. in. when 90 days old; at the end of five years the compressive strength of the blocks had risen to an average value of 4,278 lb. per sq. in. When aged for 90 days in a damp place, exposed to fire at 900 deg. Fahr. for two hours, the compressive strength fell to 2,200 lb., or a loss of 15 per cent. Blocks five years old, dry, exposed to fire at 1,700 deg. Fahr. for two hours, gave values of 1,500 to 1,900 lb. per sq. in., a loss of 50 per cent. to 65 per cent.

The loss was much more marked in the case of the 6-in. than the 8-in. cubes. It is evident that the small cubes give far too great loss in strength on heating. Some cubes allowed to stand lost much by slacking; this action has been noted by Professor Woolson in earlier tests. It should be noted also that there was a considerably greater deformation under load of the heated blocks than of those not heated.

A large number of small beams were next made, some with and some without reinforcement; most of these were either 6 in. by 6 in. by 48 in. or 8 in. by 8 in. by 48 in. The specimens which were reinforced contained four ½-in. round steel rods situated near the corners equidistant from the two faces of the beam. In some the distance from the reinforcement to the face of the beam was 1 in. and in others 1½ in. A few beams had a 2-in. protection to the reinforcement.

Three beams for example, each 6 in. by 6 in. by 48 in., in which the reinforcing rods were 1 in. from the face of the beams, were broken by center load, the first beam not having been heated at all, the second heated for one hour in a fire that fused the surface of the concrete, and the third being similarly heated for two hours. The beam which was not heated broke under a load of 5,700 lb., the second, heated for