THE VARIATION WITH THE TEMPERATURE OF THE THERMAL CONDUCTIVITY OF CAST IRON.

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Synopsis.

Variation with Temperature of the Thermal Conductivity of Soft Gray Cast Iron, 195° to 542° C.—The sample used contained 3.5, 2.2 and 0.64 per cent. of C, Si and Mn respectively, and was cast into the form of a cylindrical shell 3 cm. thick, joined with a hemi-spherical bottom. The temperature differences between the liquids inside and outside the shell, which amounted to from 3° to 6° with an input of from 0.24 to 1.6 kw, were measured with thermo-couples silver-soldered in the ends of brass tubes. Since even though these tubes were pressed against the iron surfaces, the temperatures thus measured differed more or less from the actual temperatures of the surfaces, the absolute values found for the conductivity are too low; but the results indicate that the conductivity at 542° is between 2 and 3 times its value at 195° C.

It was discovered in 1852 by J. D. Forbes (Atheneum, p. 102, 1852) that the thermal conductivity of iron was different at different temperatures. Investigations since that date have seemed to establish the fact that the conductivity of pure wrought iron decreases while that of cast iron increases with rise of temperature. This paper gives the results obtained for a specimen of soft cast iron as used in stove castings, the specimen being cast by the San Francisco Stove Works. Professor W. C. Blasdale of the chemistry department of the University of California has determined the silicon (Si) and manganese content to be 2.19 and 0.64 per cent. respectively. The carbon content was approximately 3.5 per cent.

The form of the specimen was that suggested by Mr. Carl Hering (Trans. Am. Electrochem. Soc., 18, p. 213, 1910), being a cylindrical shell with one end capped with a hemispherical shell. The dimensions of the casting were as follows: length of the circular cylindrical shell, 25.2 cm. inner diameter 6.0 cm., outer diameter 12.0 cm. The inner and outer diameters of the hemispherical cap were 6.0 and 12.0 cm. respectively. The casting was well made and after being cleaned in the lathe the thickness of the wall as measured at different points varied from 3.0 cm. by less than one per cent.

The specimen was immersed in a bath in a vessel of the same shape as the specimen. The temperature of this outer bath was subject to control as the outer vessel was provided with both a heating and a cooling coil. The interior of the specimen was filled with an electrically heated bath. Heat losses at the open end of the cylinder were prevented by keeping the temperature and temperature gradient immediately over the specimen and baths closely the same as that of the baths themselves. This was done by auxiliary heating coils, thus constituting a modified guard ring scheme. The heating element in the bath inside the specimen consisted of a graphite rod $\frac{5}{16}$ of an inch in diameter, inside a $\frac{1}{2}$ inch iron pipe, contact at the bottom of the pipe between pipe and rod being secured by having a little molten lead in the cap of the iron pipe. Asbestos string wound every few inches along the graphite rod prevented warping of the rod and insured sufficient electrical insulation. The upper ends of both the rod and the pipe were joined to heavy copper leads. The measurement of the difference in potential between the proper points in the heater system, together with the current used, gave means of determining the energy input, the power factor for this type of conductor being unity. Alternating current from a variable voltage step down transformer was used.

The temperature of the walls of the specimen was measured with four pairs of copper-constantin thermocouples, placed at various depths. The thermocouples were calibrated, using the boiling points of water, naphthalene and sulphur, the cold junctures being kept at 20° C. The thermocouples were made from No. 28 wire and special care was given to their construction. A small bulge was made near the end of a thin walled brass tube, the tube being about 4 mm. in diameter. The wires for a thermocouple, after being well annealed and joined with silver solder, were insulated with pieces of fine hard glass tubing. The couples were then inserted in the brass tube and the juncture drawn through a small hole in the center of the bulge until the glass insulation was tight against the inner wall of the tube and the juncture was in the wall of the thin brass tube. The opening was then closed with silver solder and the protruding wires cut. The end of the brass tube was then closed with a layer of asbestos and a brass plug, the union being made tight with silver solder. When in place the center of the bulge in the brass tube, and hence the juncture of the thermocouple, was pressed against the surface of the specimen. Both baths were vigorously stirred and the thermocouples gave the same readings irrespective of their depths.

Assuming radial flow of heat, mathematical analysis readily gives for this form of specimen,

$$k = \frac{aw}{Jt};$$

where k is the thermal conductivity in gram calories per deg. per cm. per sec.; w is the electrical power in watts transformed into heat within the specimen; J is the mechanical equivalent of heat; t is the fall in temperature through the wall of the specimen; and a is a constant depending on the dimensions of the specimen. It can be shown that

$$a = \frac{e\, ln \dfrac{D}{d}}{\dfrac{\pi}{2}\, dDln\, \dfrac{D}{d} + 2\pi Le},$$

e denotes the wall thickness, D the outside and d the inside diameter, L the length of the cylindrical part, ln stands for the natural logarithm. Inserting the dimensions of the specimen as given above and combining a and J we have

$$k = 0.000897\, wt.$$

For temperatures below 300° C. the baths were paraffin and above this temperature the baths were lead. The readings were made by O. R. Hull and O. S. Imhoff, working independently and about one year apart; each man making a complete new set up, including new thermocouples. It took from fifteen to thirty hours to obtain constant conditions. Readings were not accepted until conditions, as determined by the readings, had remained practically constant for at least one hour. Readings were then recorded every minute for twenty minutes and the mean taken. Since power line current was used there was a slight fluctuation in input. This fluctuation was cared for by taking most of the readings at night, and by extending the readings over a twenty-minute period, the instruments being carefully watched for the hour preceding. The results are given in the following table.

Amperes.	Volts.	Watts.	Inside Temp. C.	Outside Temp. C.	Difference t.	Mean Temp.	Conductivity k.	Thermal Ohms.	Observer.
80.....	3.00	240	197	194	3.0	195.5	0.0718	3.32	H.
81.25...	3.00	243.75	199	196.1	2.9	197.6	.0754	3.17	I.
120.....	3.50	420	287.2	283.3	3.9	285.3	.0965	2.47	H.
108.....	3.32	358.56	287	283.7	3.3	285.4	.0975	2.45	I.
120.....	3.50	420	296.8	293.1	3.7	298.6	.1018	2.35	H.
125.....	4.89	611.25	405.2	401.4	3.8	403.3	.1443	1.66	I.
128.....	5.00	640	426.6	422.9	3.7	424.8	.1552	1.54	I.
135.....	5.51	743.85	445.0	440.8	4.2	442.9	.1589	1.50	I.
165.....	6.99	1,153.35	506.5	501.1	5.4	503.8	.1916	1.25	I.
178.....	7.30	1,299.40	528.7	523.0	5.7	525.9	.2044	1.17	I.
200.....	7.91	1,582	545.2	538.6	6.6	541.9	.2050	1.16	I.

The method is open to the objection applicable to all cases where measuring the temperature of a surface is involved. What is doubtless measured in every such case is the temperature slightly away from the surface. Since the thermal resistance of the surface film of a substance is greater than for the substance itself, and since the thermal conductivity of lead is less than that of iron, it might be expected that this method would give results slightly low for any given temperature. However the variation of the conductivity with the temperature is believed to be well exemplified.

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