On The Specific Heat of Carbon Steels.

BY

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§ 1. INTRODUCTION.

Since carbon steel is a mixture of ferrite and cementite, its specific heat is the sum of the specific heat of each of the two components. The propertes of a steel are, however, much affected by temperature; accordingly, the specific heat will also be affected by it. As to the specific heat of steel, a number of observations have already been made by several investigators, such as Dieterici(1), Von Than(2), Stucker(3),

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(1) Ann. d. Phys. **33**, (1888), 417.

(2) Wied. Ann. **13**, (1881), 84.

(3) Sitzungsberichte der Wiener Akad. IIa, (1905), 657.

Harker(1), and Oberhoffer(2); but the range of temperature in the measurement of these observers was small, and as for their methods of experiments, they leave something to be desired. In regard to the heat of the transformations of steel, Osmond(3), Stansfield(4), Phinchon(5), Carpenter and Keeling(6) have also made several experiments; but they did not go far enough to exhaust the subject.

It has been already reported that A. Meuthen(7) and N. Yamada(8) have made some determinations of the heat of transformation in carbon steels by the method of mixture. One of these, A. Meuthen measured the heat content of different steels differing in carbon content, in such a way that a specimen was heated to each temperature in a vacuum furnace, and the change of heat content in the A_1, A_2, and A_3 transformations was determined by the heat quantity which the specimen gave out to the calorimeter.

The other, N. Yamada, obtained the change of heat content during the transformation of martensite to pearlite by measuring the heat evolved in the vicinity of 400°C during tempering; at the same time, he was able to obtain the heat of the allotropic change, that is, the transformation from austenite to martensite, by combining his result with Meuthen's. Meuthen's experiment was made with specimens of twelve kinds varying in carbon content ranging from 0.06 % to 4.03 %, and the range of temperature covered was only from 600°C to about 900°C.

According to the theory of quenching put forward by Prof. K. Honda(9), during cooling the A_1 transformation in carbon steel consists of a stepped change, that is,

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(1) Phil. Mag., (6), **10**, (1905), 430.
(2) Metallurgie **4**, (1907), 427.
(3) C. R. **103**, (1886), 743, 1135.
(4) Jour. Iron & Steel Inst., No. 2, (1899), 169.
(5) Ann. de Chim. et de Phys., (6), **11**, (1887), 33.
(6) Jour. Iron and Steel Inst., No. 1, (1904), 224.
(7) Ferrum, **10**, (1912), 1.
(8) Sci. Rep., **10**, (1922), 453; Jour. Iron and Steel Inst., No. 1, (1922), 409.
(9) Sci. Rep., **8**, (1919), 181.

Austenite → martensite → pearlite.

On a slow cooling of a carbon steel, for example, one containing 0.9 % of carbon, from a temperature above the A_1 point, the austenite —a solid solution of carbon in γ-iron—undergoes at first an allotropic change being transformed into martensite, which is also a solid solution of carbon in α-iron; but as soon as the martensite is formed, it immediately changes into pearlite, the result being the same as austenite→ pearlite. During a very rapid cooling, such as is caused by quenching in water, the change from austenite to martensite is so far retarded that it begins to take place at a temperature below 300°C, and when this change is completed, the specimen which has been subjected to this treatment is nearly at room temperature, and hence the second change from martensite to pearlite cannot take place, owing to the great viscosity of the specimen at this temperature. Thus martensite can be obtained by quenching the steel in water. The heat of the A_1 transformation is therefore the sum of the heat of the A_3 allotropic change and that of the precipitation of cementite from iron. The total heat of the A_1 transformation can be determined by measuring the difference in the heat content of both austenite and of pearlite above and below the A_1 transformation.

To determine the heat content at each temperature within the range from 100～1250°C the present writer has made several experiments with carbon steels of different content of carbon and undertook to find the specific heat of carbon steel with reference to the carbon concentration and the heat of transformation from the specific heat-temperature curve.

§ 2. ARRANGEMENT AND METHOD OF EXPERIMENT.

The arrangement used in the present experiments being almost the same as that constructed by Dr. Y. Tadokoro,⁽¹⁾ no particulars will here

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(1) Sci. Rep., **10**, (1921), 352.

be necessary. The calorimeter, being a thin copper vessel of a cylindrical form, the inside of which is plated with silver, is filled with 500 grs. of distilled water, which fills about three-quarters of the vessel. The vessel is heated by an electric current passing through the coil wound round it during the experiment, in order to keep it at a constant temperature, and at the same time, the room was closely shut and its temperature was also kept constant at about 23°C all the time.

The rise of the temperature of the calorimeter was measured by two Beckmann thermometers, of which one has a graduation of one hundredth of a degree centigrade and the other of one tenth of a degree; they were read through a room telescope. The specimen is placed on a cross-formed support made of platinum wire and can be easily allowed to fall freely into the calorimeter by a slight oscillation of the wire. The heating furnace, being 4 cm. in internal diameter and 18 cm. in length, is held vertically and is heated uniformly. The specimen is suspended by the cross-formed support in the middle of this electric furnace and its temperature, within 100°C or 200°C, is measured by a mercury thermometer in contact with the specimen in the same position.

Both ends of the furnace are closely covered with fire-proof materials and a small hole is made in the wall of the lower side of the furnace to let pass a purified hydrogen gas in order to avoid the oxidation of the specimen at high temperatures.

The temperature of the specimen is kept constant at the required height for about 15 minutes. When the temperature of the calorimeter begins to remain constant at nearly 23°C, the water in the calorimeter being constantly stirred by a stirrer driven by a small motor, the furnace is rapidly brought right over the calorimeter on rails, and the heated specimen is allowed to fall immediately into the calorimeter by a slight oscillation of the platinum holder; then the cover of the calorimeter and that of the furnace are shut and the furnace is rapidly brought back to its former position. The time needed for this process is only about 3 seconds, while the furnace remains over the calorimeter for about a second.

The rise of the temperature of the calorimeter is read every 5 seconds for about 15 minutes, during which the water in the calorimeter is always stirred by the regular rotation of the stirrer.

The temperature-time curve of the calorimeter rises rapidly at first and reaches a maximum, after which it slightly falls almost linearly. This portion of the curve, if produced backwards, cuts the axis of temperature at a certain height; this height corresponds to the temperature raised by the quantity of heat given off by the specimen, any external loss of heat being excluded.

For the determination of the water equivalent of the calorimeter, specimens of an electrolytic copper and pure silver were used. Taking the specific heat of these metals as 0.093 and 0.056 respectively, we obtained 25.2 and 24.9 as the value of the water-equivalent.

These results were obtained by heating the specimens to 150°C, but, in order to ascertain the water-equivalent-temperature relation, the present writer determined the water-equivalent by measuring the heat quantity given out by an electric current passing through a nichrome wire. The measurement was made after every increase of 200 calories, until the heat quantity reached 2600 calories.

The results of the respective measurements are as follows:—

25.0, 25.2, 24.8, 24.9, 24.2, 25.8, 25.3, 24.8;

on the other hand, a value 24.9 was obtained as the water-equivalent from the weight and the specific heat of copper, glass and mercury. From these facts, we adopted 25.0 as the value of the water-equivalent, and it is reasonable to assume that the water-equivalent is independent of temperature in the range of the present experiment.

The following is the formula used for the calculation of the mean specific heat of the specimen:—

$$c = \frac{(w+W)(t_2-t_0)}{m(t_1-t_2)},$$

where c = mean specific heat of the specimen,

w = water-equivalent of the calorimeter,

W = mass of water in the calorimeter,

m = mass of the specimen,

t_0 = initial temperature of water in the calorimeter,

t_1 = temperature of the specimen heated,

t_2 = final temperature of the water in the calorimeter raised by the heated specimen.

In the above observation it was only the specimen that was let fall into the calorimeter, so that the calculation was thus simplified.

§ 3. PREPARATION OF THE SPECIMENS.

The present experiment was made with specimens of twelve kinds of steel, the carbon content varying from 0.09 to 2.84 %. The specimens, all having the same size and shape, were 10 mm. in diameter and 30 mm. in length. They were about fifteen in number and prepared from carbon steel with the same composition. Each specimen was measured 3 to 4 times respectively. As it was necessary to carry out the observation under the same conditions, each specimen was annealed at 900°C. As to the specific heat of steel, as has already been explained by Prof. K. Honda⁽¹⁾, its value varies according to the heat treatment of steels before measurement; such as, forging, annealing and normalizing. In forged specimens the mean specific heat-concentration curves at 0°C and 650–700°C as obtained by A. Meuthen, consist of two straight-lines cutting each other at the vicinity of the eutectoid concentration.

While, for the annealed specimen, the specific heat below the A_1

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(1) Sci. Rep., **12**, (1924), 347.

point, increases in proportion to the contents of carbon or cementite. In the present experiment, the mean specific heat of the specimen was obtained from the heat content given off by the specimen, when it was let fall into the calorimeter from a certain high temperature. It was also observed that the structure of the specimen changed when dropped from a temperature above the A_1 point.

Even beyond the A_1 point, if the temperature is comparatively low, the structure is sometimes troostitic or troosto-sorbitic. The structure differs more or less in character, as the carbon content varies. For the formation of the martensitic structure, different high temperatures were required according to the carbon content. Within the range of the present experiment, i. e. up to 1050°C, all the specimens that were let fall into the water showed no austenitic structure. As a purified hydrogen gas was continuously passed through the furnace, no oxidation of the specimens could be observed. The specimen did not show any perceptible difference in weight at each measurement. The analysis of the specimens used in the present investigation is as follows:—

No.	C	Mn	Si	P	S	Cu
1	0.09	0.35	—	0.015	0.041	—
2	0.224	0.299	0.124	0.026	0.023	0.341
3	0.30	0.80	0.215	0.021	0.022	0.68
4	0.54	0.91	0.122	0.047	0.024	—
5	0.61	0.77	0.146	0.028	0.019	—
6	0.795	0.11	0.228	0.023	0.015	0.15
7	0.994	0.09	0.270	0.032	0.020	0.059
8	0.92	0.14	0.45	0.015	0.016	0.014
9	1.235	0.08	0.325	0.032	0.012	0.045
10	1.41	0.67	0.091	—	—	—
11	1.575	0.08	0.58	0.028	0.012	0.045
12	2.84	0.56	1.04	0.256	0.056	—

§ 4. RESULTS OF EXPERIMENTS.

I. General result.

The results of the present experiments are tabulated below :—

0.09 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.10	0.1110	750	112.9	0.1504
200	22.8	0.1140	770	118.0	0.1532
300	35.4	0.1181	800	127.0	0.1588
400	40.0	0.1225	850	140.4	0.1650
500	63.4	0.1268	900	152.3	0.1691
600	81.0	0.1350	1000	168.9	0.1689
700	100.1	0.1430	1100	186.0	0.1689
710	102.2	0.1441	1200	203.1	0.1690
730	108.2	0.1482	1250	211.5	0.1691

0.224 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.1	0.1113	750	115.5	0.1540
200	22.8	0.1143	770	120.4	0.1565
300	35.8	0.1193	800	129.6	0.1620
400	49.2	0.1219	850	142.5	0.1678
500	63.7	0.1273	900	150.8	0.1678
600	81.2	0.1354	1000	167.6	0.1676
700	100.2	0.1432	1100	184.5	0.1678
710	102.3	0.1441	1200	201.7	0.1693
730	110.9	0.1520	1250	210.2	0.1685

0.30 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.2	0.1115	750	116.6	0.1555
200	22.9	0.1148	770	121.4	0.1578
300	36.0	0.1200	800	131.5	0.1646
400	49.3	0.1233	850	142.1	0.1673
500	63.9	0.1278	900	150.0	0.1668
600	81.4	0.1357	1000	166.9	0.1669
700	100.5	0.1436	1100	183.8	0.1670
710	102.5	0.1443	1200	201.0	0.1676
730	112.3	0.1540	1250	209.6	0.1674

0.54 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.3	0.1125	750	121.1	0.1615
200	22.9	0.1149	770	125.5	0.1630
300	36.2	0.1207	800	131.5	0.1645
400	49.9	0.1248	850	140.0	0.1648
500	64.1	0.1282	900	148.1	0.1647
600	82.0	0.1366	1000	164.6	0.1646
700	101.0	0.1443	1100	181.7	0.1650
710	103.0	0.1451	1200	198.6	0.1657
730	116.8	0.1600	1250	207.5	0.1660

0.61 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.4	0.1142	750	122.0	0.1627
200	23.0	0.1157	770	126.1	0.1639
300	36.5	0.1217	800	130.8	0.1636
400	50.1	0.1253	850	139.6	0.1644
500	64.3	0.1286	900	147.3	0.1639
600	82.1	0.1368	1000	164.0	0.1640
700	101.2	0.1446	1100	180.9	0.1645
710	103.2	0.1454	1200	198.0	0.1650
730	118.0	0.1615	1250	206.9	0.1657

0.795 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.5	0.1153	750	123.5	0.1648
200	23.1	0.1160	770	126.1	0.1640
300	36.9	0.1230	800	129.5	0.1620
400	50.2	0.1255	850	138.0	0.0624
500	64.8	0.1298	900	145.9	0.1620
600	82.3	0.1373	1000	162.2	0.1622
700	101.4	0.1449	1100	179.0	0.1629
710	103.5	0.1459	1200	196.1	0.1635
730	120.6	0.1653	1250	204.5	0.1638

0.92 % C.

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.6	0.1159	750	124.1	0.1656
200	23.6	0.1180	770	126.5	0.1644
300	36.9	0.1230	800	130.0	0.1625
400	50.3	0.1256	850	137.0	0.1612
500	65.0	0.1301	900	144.7	0.1607
600	82.5	0.1375	1000	160.8	0.1608
700	101.6	0.1451	1100	177.9	0.1616
710	103.7	0.1461	1200	194.2	0.1618
730	122.1	0 1674	1250	202.9	0.1620

0.994 % C.

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.6	0.1162	750	124.0	0.1653
200	23.7	0.1185	770	126.6	0.1646
300	36.9	0.1230	800	130.0	0.1625
400	50.4	0.1260	850	136.2	0.1604
500	65.0	0.1300	900	144.5	0.1606
600	82.7	0.1380	1000	160.2	0.1602
700	101.9	0.1456	1100	177.0	0.1610
710	103.9	0.1463	1200	192.1	0.1600
730	122.0	0.1671	1250	201.0	0.1610

1.235 % C.

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	11.8	0.1173	750	125.0	0.1666
200	23.9	0.1195	770	127.0	0.1650
300	37.0	0.1233	800	131.0	0.1640
400	50.9	0.1273	850	136.2	0.1604
500	65.5	0.1310	900	144.0	0.1600
600	83.0	0.1383	1000	157.9	0.1579
700	102.2	0.1460	1100	174.9	0.1590
710	104.2	0.1468	1200	190.0	0.1584
730	122.0	0.1670	1250	199.0	0.1592

1.41 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	12.0	0.1181	750	124.6	0.1661
200	24.0	0.1200	770	127.3	0.1653
300	37.2	0.1240	800	131.4	0.1643
400	51.0	0.1275	850	138.0	0.1625
500	65.9	0.1318	900	144.0	0.1600
600	83.5	0.1391	1000	156.1	0.1561
700	102.7	0.1467	1100	173.1	0.1575
710	104.7	0.1475	1200	189.0	0.1575
730	122.0	0.1673	1250	197.0	0.1577

1.575 % *C.*

Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	12.0	0.1190	750	125.0	0.1666
200	24.1	0.1205	770	128.1	0.1663
300	37.5	0.1250	800	132.3	0.1654
400	51.1	0.1278	850	139.4	0.1640
500	66.1	0.1322	900	146.6	0.1630
600	83.9	0.1398	1000	160.0	0.1600
700	103.0	0.1471	1100	172.0	0.1564
710	105.0	0.1475	1200	187.0	0.1559
730	122.0	0.1673	1250	195.3	0.1564

2.84 % *C.*

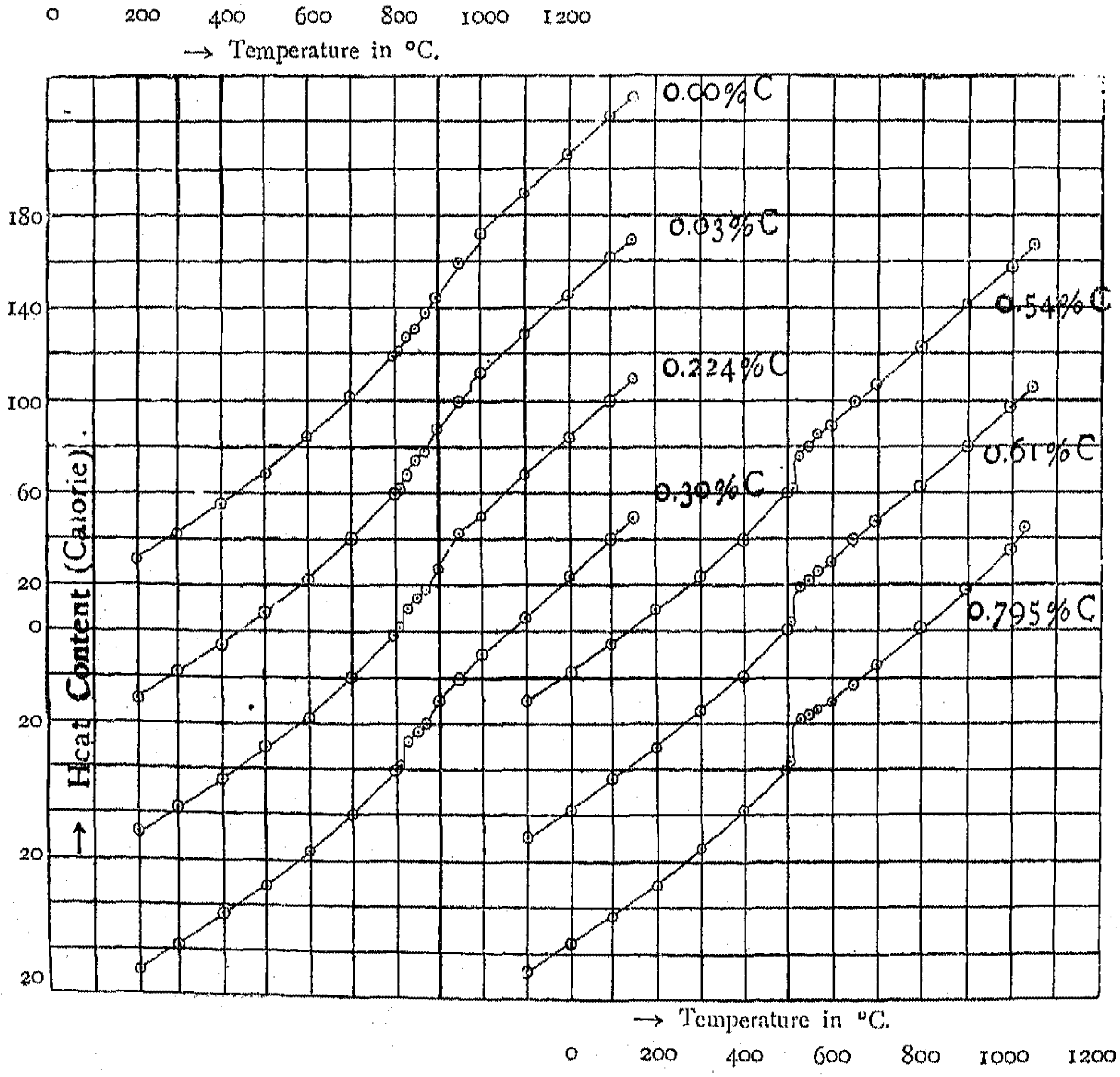
Temp.	Total calorie	Mean sp. heat	Temp.	Total calorie	Mean sp. heat
100	12.5	0.1248	750	124.5	0.1660
200	25.4	0.1270	770	127.8	0.1661
300	39.0	0.1301	800	132.4	0.1656
400	53.0	0.1325	850	140.3	0.1651
500	68.5	0.1370	900	148.2	0.1649
600	85.8	0.1430	1000	164.4	0.1644
700	105.3	0.1504	1100	175.0	0.1590
710	107.2	0.1507	1200	187.0	0.1560
730	121.5	0.1663	1250	192.5	0.1542

In the above tables, each value is the mean of three to five observations at each temperature. In most cases, the deviation in the result of any one observation from the mean value did not exceed 1 percent, but in the most unfavourable case, it was 1.3 percent. Though the oxidation of the specimen was satisfactorily prevented by passing a purified hydrogen gas through the furnace, it was sometimes observed that the specimen cracked when quenched from a high temperature. This phenomenon, however, did not cause any sensible error in the measurement of the specific heat.

Fig. 1.

Heat Content Curve.

(0.00 % C..........0.795 % C)

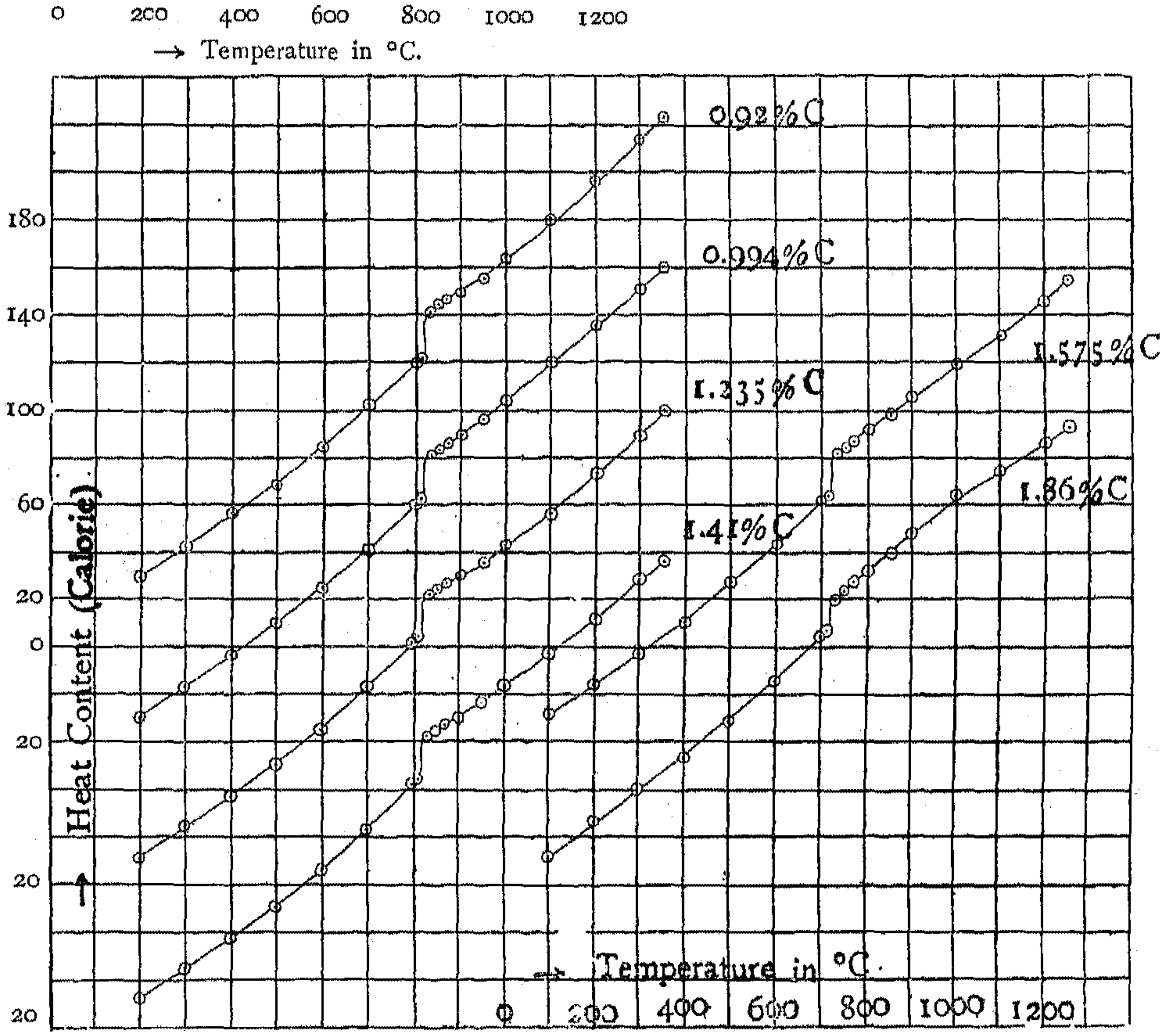


Figs. 1 and 2 show the relation between the heat capacity and the temperature for different specimens. The mean specific heat-temperature

Fig. 2.

Heat Content Curve.

(0.92 % C............2.84 % C)



relation is shown in Figs. 3 and 4. From the relation between the heat capacity and the carbon concentration, at each temperature, as shown in Fig. 5, the specific heat of pure iron at different temperatures was obtained by extrapolation. Thus the curve representing the relation between the heat capacity and the temperature in pure iron can be considered as made up of two parts, that is, a quadratic curve and a straight line separated by a short discontinuity at the A_3 point. But,

Fig. 3.

Mean Specific Heat.

(0.00 % C...........0.795 % C)

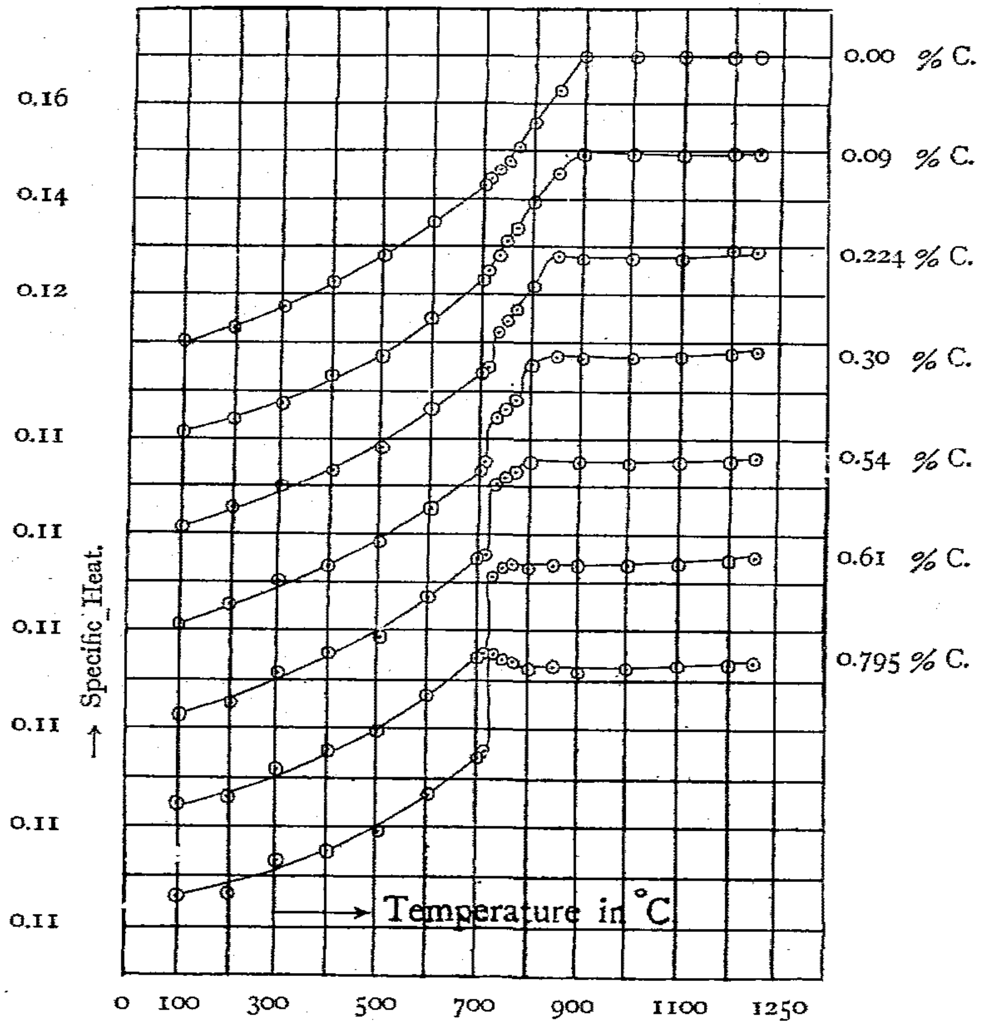


Fig. 4.

Mean Specific Heat.

(0.92 % C...........2.84 % C)

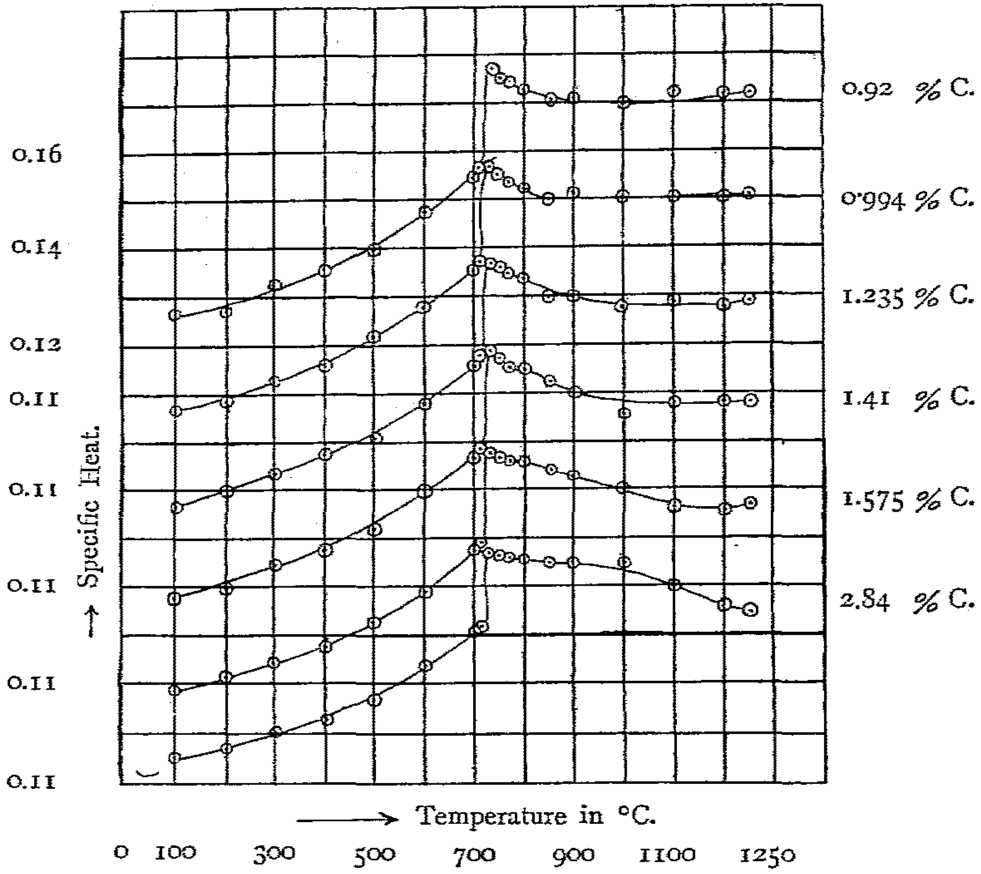
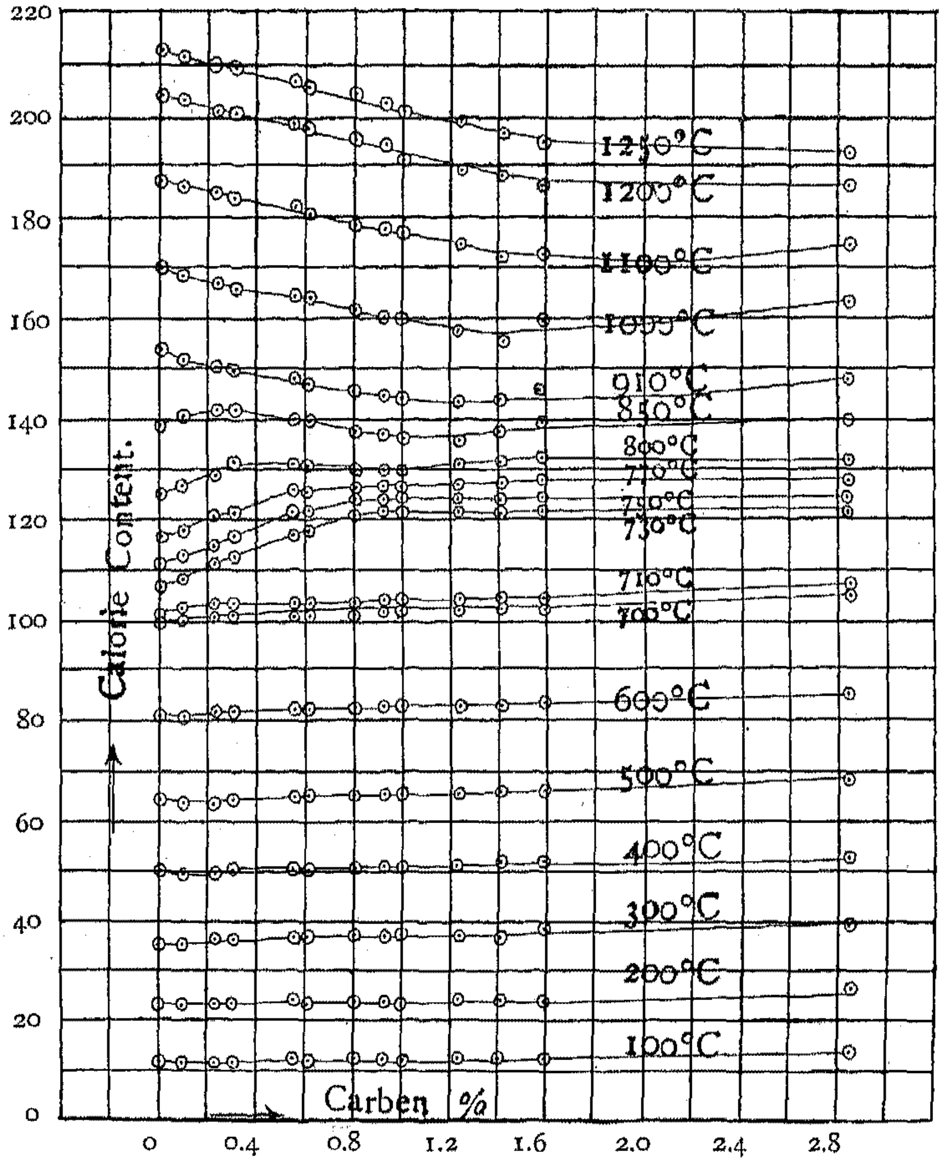


Fig. 5.



with the increase of the carbon content, another discontinuity takes place at the A_1 point and a conspicuous change is observed in the heat content of the specimen above and below this point. It is also observable that the heat content curve shows somewhat different inclinations with the rise of temperature. Above the A_1 point, the rate of cooling of the specimen becomes more and more rapid with the rise of temperature, and therefore, the structure becomes martensitic. Accordingly the heat content in this region is the quantity of heat of the transformation from austenite to martensite, but as the specific heat means the total quantity of heat required by a specimen of normal structure to reach a certain high temperature, for the measurements above the A_1 point, the due correction for the heat content of the transformation from martensite to pearlite should be made. This correction will be referred to later on.

II (a). Specific heat below the A_1 point.

It is generally considered that the heat capacity-temperature curve consists of a quadratic form below the A_1 point. If Q be the heat capacity of the specimen, the true specific heat at any temperature T will be given by:—

$$\text{True specific heat} = \left(\frac{dQ}{dt}\right)_T,$$

that is, the value of the tangent drawn at a point on the heat capacity-temperature curve gives the true specific heat at the temperature corresponding to the point. From the values thus found, it is to be concluded that the true specific heat increases with the rise of temperature.

According to A. Meuthen⁽¹⁾, the true specific heat below the A_1 point has a definite value independent of the temperature. In his observation, however, the range of temperature in the measurement was too small; but in our experiment, the range of the observation was extended from room temperature to 710°C, and it was found that the true specific heat varied with the temperature.

It is observed that, in pure iron, the heat content curve below 800°C and that above 900°C, if they are produced, cut the same ordinate at two points at a little distance from each other. This discontinuity corresponds to the heat of the A_3 transformation. In steels the gradient of the heat content curve below the A_1 point increases with the rise of temperature; that is, below the A_1 point, the true specific heat linearly increases with temperature, and as will be explained later on, it remains nearly contant above the A_1 point up to 1250°C.

Next, referring to the curves in Fig. 5 for the heat capacity-concentration relation, we find that below the A_1 point, there is no

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(1) Fer., **10**, (1912), 17.

break at the eutectoid concentration as observed by A. Meuthen(1). M. Levin and H. Schottky(2) also found that the specific heat-concentration curves for various steels annealed for 24 hours at 650°C is linear, showing no break in the vicinity of the eutectoid concentration. Prof. K. Honda(3) found also the same linear relation in a range of temperature between 20°C and 150°C.

These results confirm the view that since steel is composed of a mechanical mixture of ferrite and cementite, the specific heat carbon-concentration curve must be linear.

(b). Specific heat of pure iron or ferrite.

The following table was obtained from the observed results for different carbon steels by the extrapolation to carbon concentration zero.

Temp.	Total calorie	Mean sp. heat	True sp. heat Cp.	Cv	Atomic heat
100	11.0	0.1100	0.1150	0.1128	6.30
200	22.6	0.1130	0.1218	0.1188	6.64
300	35.2	0.1173	0.1309	0.1274	7.12
400	48.8	0.1222	0.1431	0.1390	7.77
500	63.7	0.1275	0.1579	0.1532	8.56
600	81.0	0.1350	0.1774	0.1721	9.62
700	99.8	0.1426	0.2102	0.2043	11.42
750	111.0	0.1480	0.2430	0.2368	13.24
800	125.0	0.1564	0.2710	0.2644	14.78
825			0.2760	0.2693	15.05
850	138.8	0.1633	0.1690	0.1621	9.06
900	152.9	0.1700	0.1700	0.1628	9.10
925	157.2	0.1699	0.1680	0.1547	8.65
950	161.3	0.1698	0.1690	0.1615	9.03
1000	169.8	0.1698	0.1660	0.1582	8.85
1100	186.9	0.1699	0.1660	0.1576	8.80
1200	203.5	0.1698	0.1660	0.1569	8.76
1225	208.3	0.1700	0.1660	0.1567	8.75
1250	212.2	0.1700			

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(1) Fer., **10**, (1913), 196.

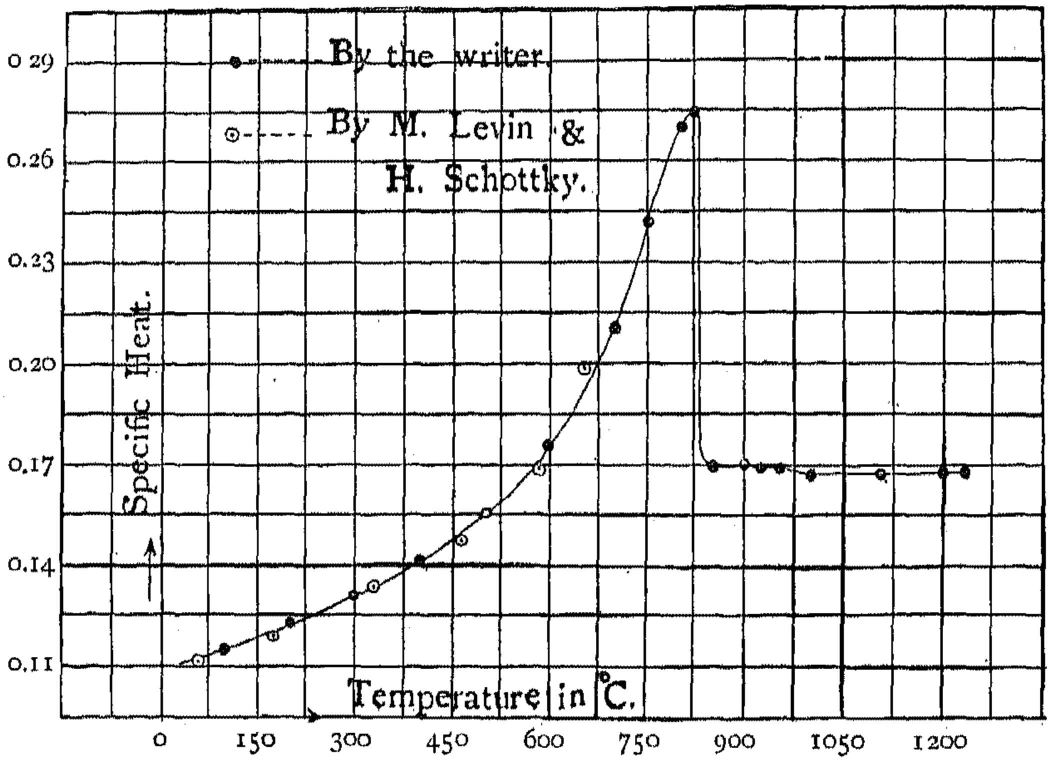
(2) l. c.

(3) l. c.

These results together with those of M. Levin and H. Schottky have been shown in Fig. 6. Their results below 700°C almost coincide with those of the present writer. Above 700°C, the true specific heat increases rapidly, and abruptly decreases from 850°C, while it remains constant above 900°C. As to be expected, the form of the true specifiic heat-temperature curve is exactly similar to the heat evolution-temperature curve in the thermal analysis. By using the thermodynamical relation, the specific heat at constant pressure was reduced so that at constant volume, and the results are given in the sixth column in the above table. The last column in the same table shows the atomic heats of pure iron at different temperatures. It is worth noticing that at very high temperatures, the value of the atomic heat is considerably larger than the theoretical value $3R = 5.96$.

Fig. 6.

True Specific Heat of Pure Iron.



(c). Specific heat of electric carbon poles.

It has been already remarked that the specific heat of iron is affected by its carbon content. The present writer undertook therefore the determination of the specific heat of carbon for the purpose of revealing how the specific heat of cementite, a compound of iron and carbon, is connected with that of each of its constituents. Several carbon poles, about 3–4 grs. in weight, were taken as the test specimens, and their specific heat measured. The specimen was covered with asbestos paper to protect it from oxidation, while a purified hydrogen gas was passed continuously through the furnace. The correction of the asbestos to the specific heat was of course applied.

The specimen was kept in a desiccator in order to keep the quantity of moisture absorbed by the specimen constant. It was weighed every other day, and if there was no difference of weight after several days' measurements, it was placed in the furnace and the measurement was made. After the experiment it was well dried and again placed in the desiccator. Then it was again weighed every other day, till it reached a constant value; the difference in the weights before and after the experiment was taken as being the loss of carbon during the experiment, and this difference was used for the correction of the specific heat.

Observations at different temperatures were made with the specimens taken from the same carbon pole, its specific density being 1.53; its analysis after the experiment was as follows:—

C	SiO_2	Fe_2C_3	H_2O	Ignition residue
97.800	0.123	0.243	1.000	0.340

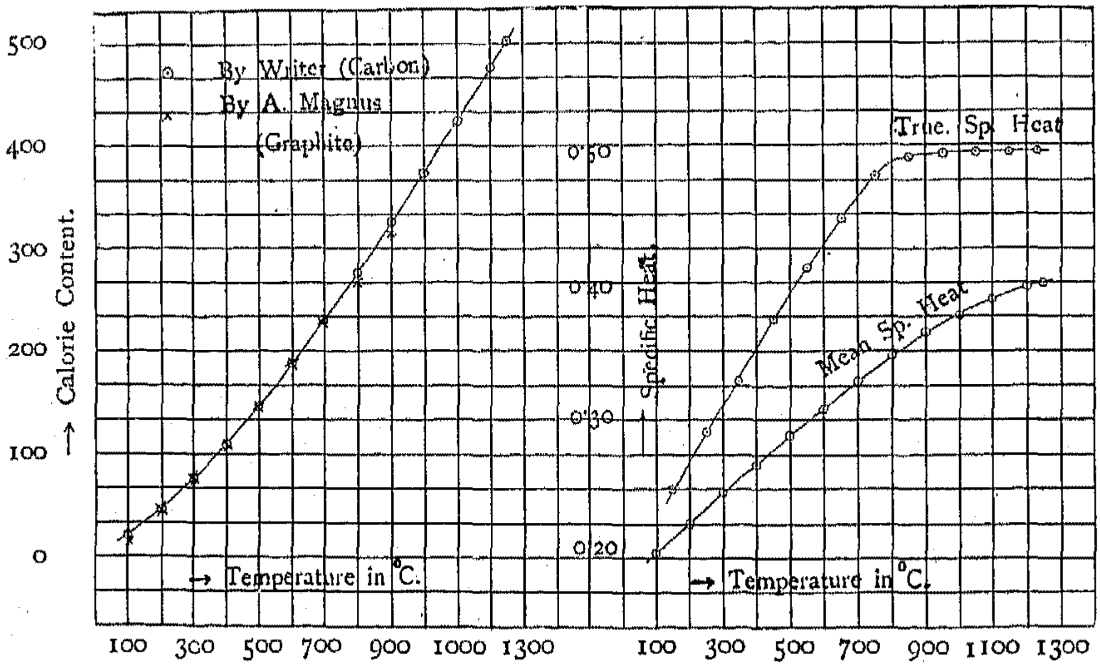
Considering the fact that the difference between the weights before and after observation amounts to nearly 0.5~1 0 percent, it will be concluded that the carbon content in the pole is 98 to 99 percent.

The following table contains the heat content and the mean specific heat, together with the loss of carbon during the observation.

Temp.	Heat content (cal.)	Mean sp. heat (ob).	Loss %	Mean sp. (corr.)
100	20.24	0.2023	0.05	0.2024
200	44.96	0.2245	0.12	0.2248
300	74.01	0.2461	0.25	0.2467
400	106.84	0.2667	0.33	0.2671
500	143.25	0.2857	0.26	0.2865
600	184.20	0.3060	0.30	0.3070
700	228.97	0.3261	0.29	0.3271
800	276.80	0.3445	0 41	0.3460
900	325.71	0.3607	0.33	0.3619
1000	375.50	0.3721	0.90	0.3755
1100	424.60	0.3820	1.06	0.3860
1200	474.24	0.3896	1.42	0.3952
1250	499.00	0.3939	1.70	0.3992

These results show that the quantity of carbon lost during the observation is very small and it is only those above 1100°C that exceed one percent. They are also shown in Fig. 7. The approximate figures for the true specific heat can be obtained from the curves of the mean

Fig. 7.


Heat Content Curve of Carbon.

Specific Heat of Carbon.

specific heat; the results of calculation together with those of A. Magnus'(1) are given in the following table:—

Comparison of the specific heat of carbon
with that of graphite.

Temp.	Mean sp. heat (the writer)	Mean sp. heat (A. Magnus)	True sp. heat Cp (the writer)	True sp. heat Cv	Atomic heat
100	0.2024	0.1865			
150			0.2468	0.2467	2.96
200	0.2248	0.2183			
250			0.2910	0.2909	3.49
300	0.2467	0.2464			
350			0.3343	0.3341	4.01
400	0.2671	0.2703			
450			0.3742	0.3740	4.49
500	0.2865	0.2914			
550			0.4118	0.4116	4.94
600	0.3070	0.3088			
650			0.4474	0.4471	5.36
700	0.3271	0.3242			
750			0.4766	0.4763	5.72
800	0.3460	0.3371			
850			0.4911	0.4908	5.89
900	0.3619	0.3485			
950			0.4941	0.4938	5.93
1000	0.3755				
1050			0.4948	0.4944	5.94
1100	0.3860				
1150			0.4954	0.4950	5.94
1200	0.3952				
1225			0.4953	0.4949	5.94
1250	0.3992				

Thus, these two observations made by Magnus and the present writer nearly coincide with each other, but below 200°C and above 700°C, the value obtained by the former is a little smaller than that obtained by the latter.

In the case of the writer's experiment, the true specific heat (Cp or Cv) uniformly increases at first, and above 600°C, its rate becomes gradually less, till it reaches almost a constant value above 900°C. The atomic heat of carbon increases with the rise of temperature and approaches the theoretical value of $3R = 5.96$ above 1200°C.

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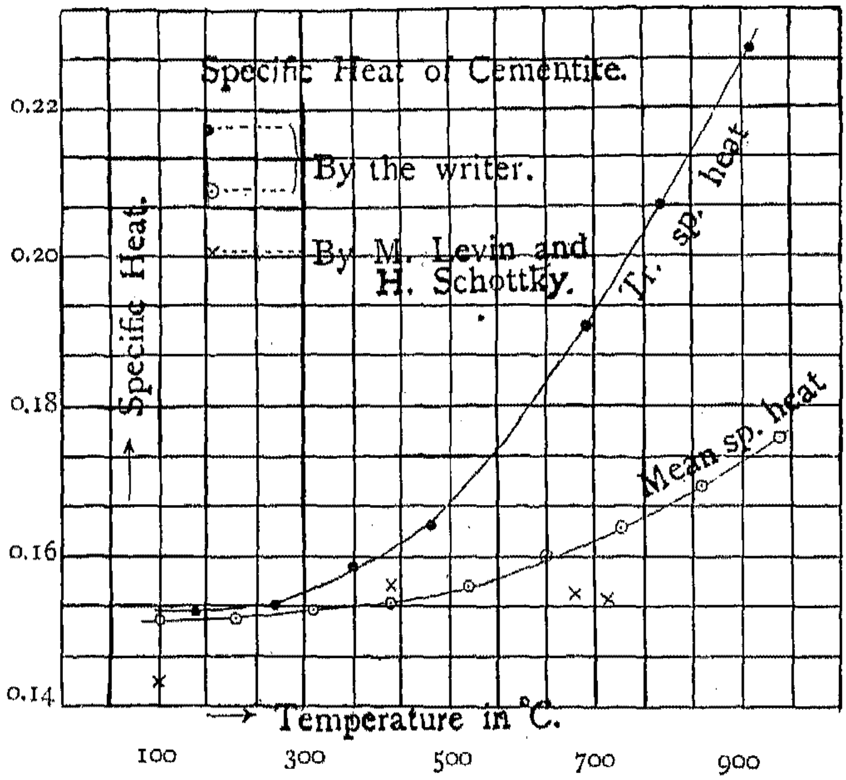
(1) Ann. d. Phys., **70**, (1922), 303.

(d). Specific heat of cementite.

From the heat capacity-concentration curves shown in Fig. 5, the heat content of cementite in the range from 20 to 900°C, can be obtained by extrapolation. From these numbers, the true or mean specific heat at different temperatures can be calculated; the results of calculation are given below and also in Fig. 8.

Fig. 8.



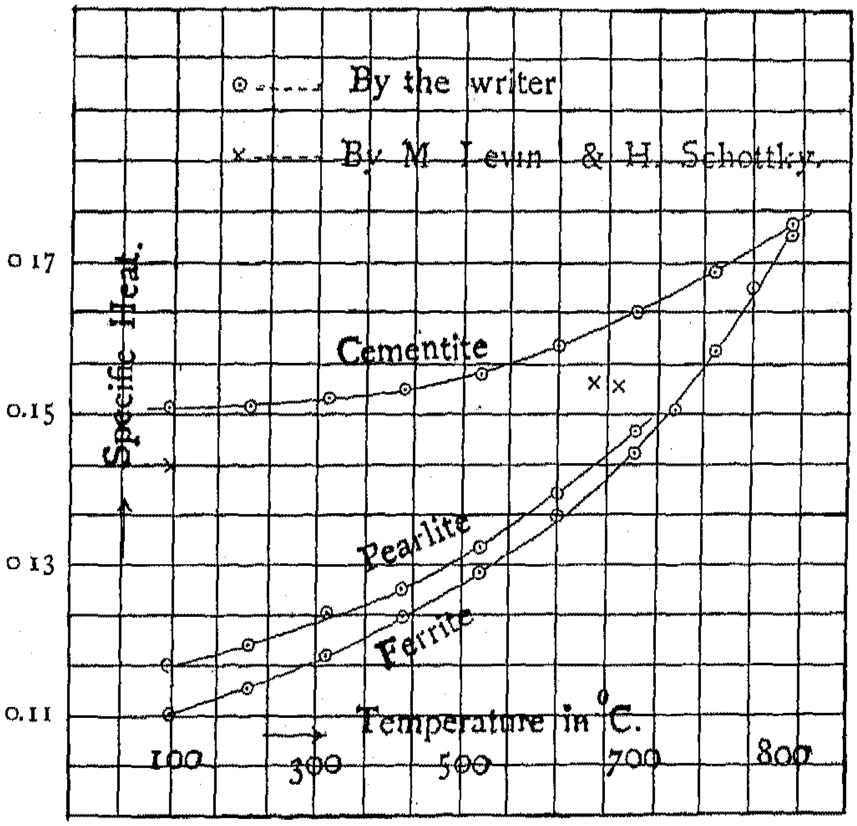
Specific heat of Cementite.

Temp.	Heat content	Mean sp. heat	True sp. heat
100	14.8	0.1480	
150			0.149
200	29.7	0.1485	
250			0.150
300	44.7	0.1490	
350			0.155
400	60.2	0.1505	
450			0.160
500	76.2	0.1524	
550			0.172
600	93.4	0.1557	
650			0.185
700	111.9	0.1599	
750			0.200
800	131.9	0.1649	
850			0.220
900	153.9	0.1710	

Prof. K. Honda also determined the specific heat of cementite in a similar way, and obtained a value of 0.151 at 20~150°C, which result only differs from ours by 1.3 percent. The result of M. Levin and H. Schottky(18) is also included in the same figure; the points of their observation lie a little below those of ours. In our observations the true or mean specific heat gradually increases with the rise of temperature, that is, up to 300~400°C, it increases slowly and afterwards more rapidly. The mean and true specific heats of ferrite, pearlite (0.9 % C steel) and cementite are graphically shown in Figs. 9 and 10.

Fig. 9.

Mean Specific Heat.



From these figures it will be seen that the mean specific heat of cementite is much greater than that of ferrite or pearlite at room temperature, but as the temperature rises, this difference becomes less. As shown in Fig. 10, the true specific heat of ferrite and cementite increases at a different rate, with the rise of temperature, and their curves intersect with each other at about 600°C. The following is the comparison of

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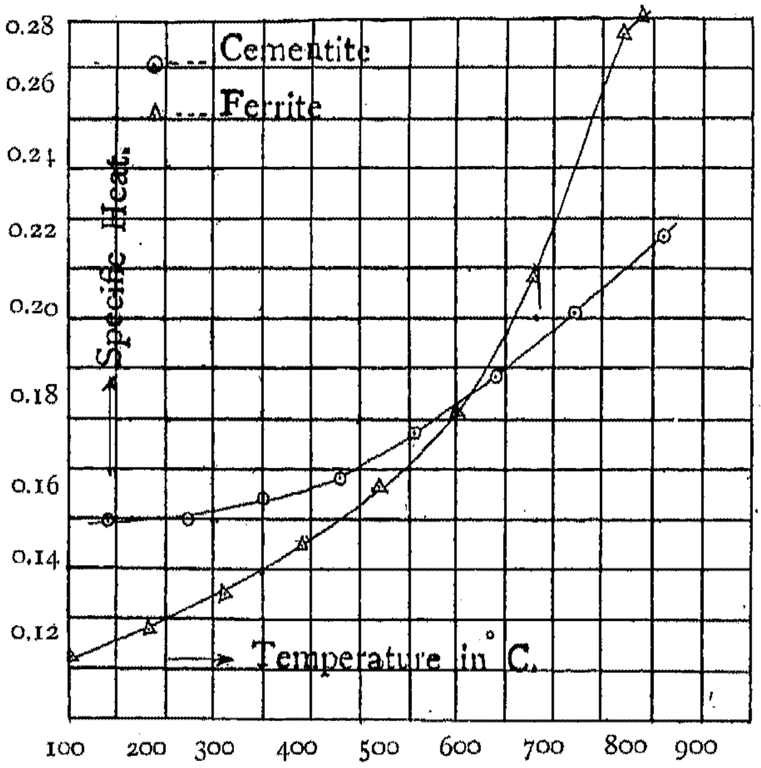
(18) Fer., **7**, (1913), 205.

the specific heat of cementite with the sum of those of the constituents, that is, iron and carbon.

Fig. 10.

True Specific Heat.



Specific heat of cementite and $3Fe+C$.

Temp.	Mean specific heat	
	Fe_3C	$3Fe+C$
100	0.1480	0.1161
200	0.1485	0.1212
300	0.1490	0.1254
400	0.1505	0.1319
500	0.1524	0.1381
600	0.1557	0.1465
700	0.1599	0.1543
800	0.1649	0.1691
900	0.1710	0.1828
1000		0.1833
1100		0.1837
1200		0.1843
1250		0.1849

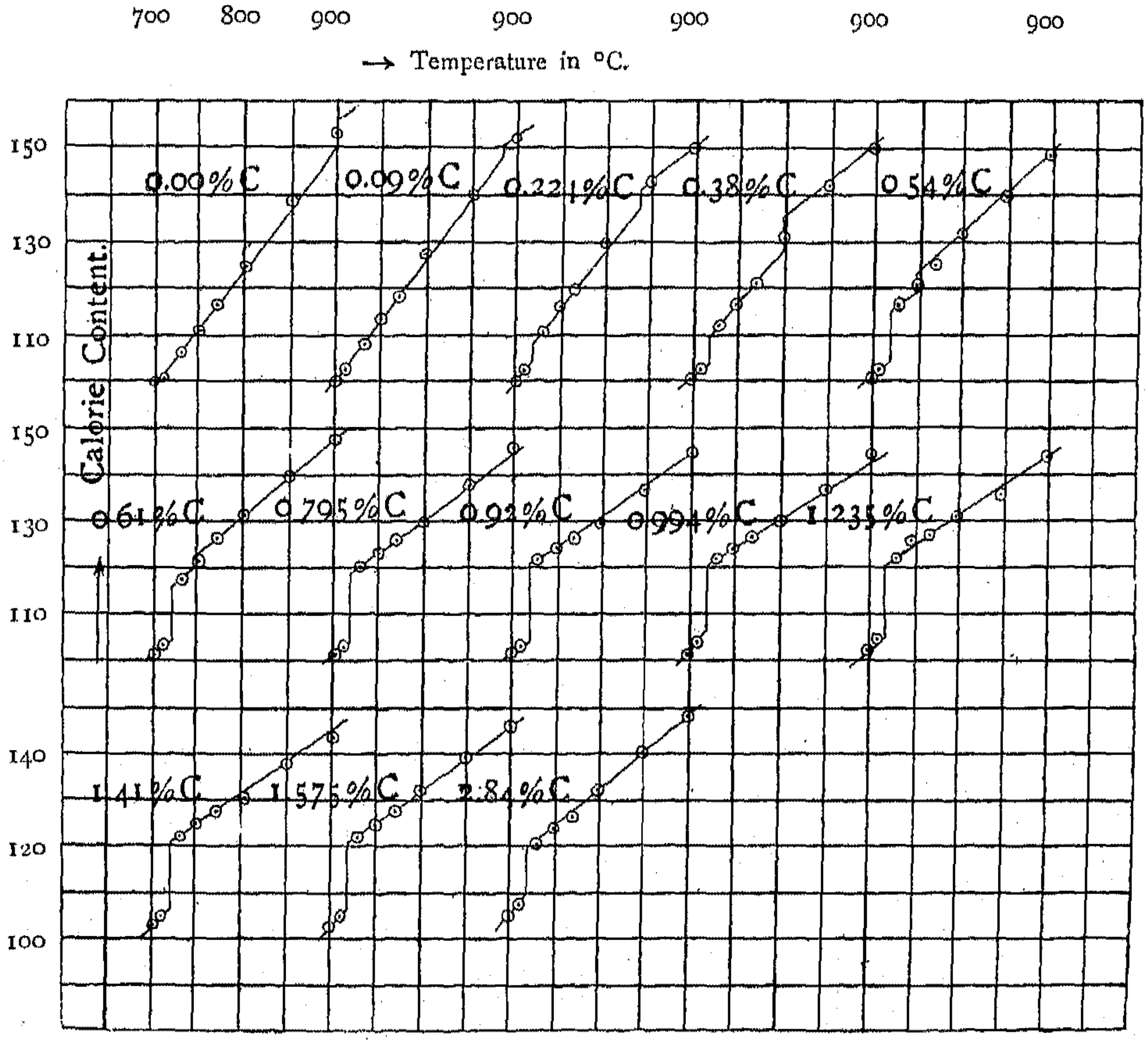
From the above table, it will be seen that the mean specific heat of cementite is greater than that of the mixture, this difference becoming less as the temperature rises, and above 800°C, the specific heat of the former is less than that of the latter.

III (a). Specific heat in the range from the A_1 to the A_3 point.

At the A_1 point, the heat quantity corresponding to the sum of the heat of the allotropic change and that required for the precipitation of cementite in iron should manifest itself, and hence a conspicuous evolution of heat takes place at this point, as is actually observed (Fig. 1). Hence

Fig. 11.

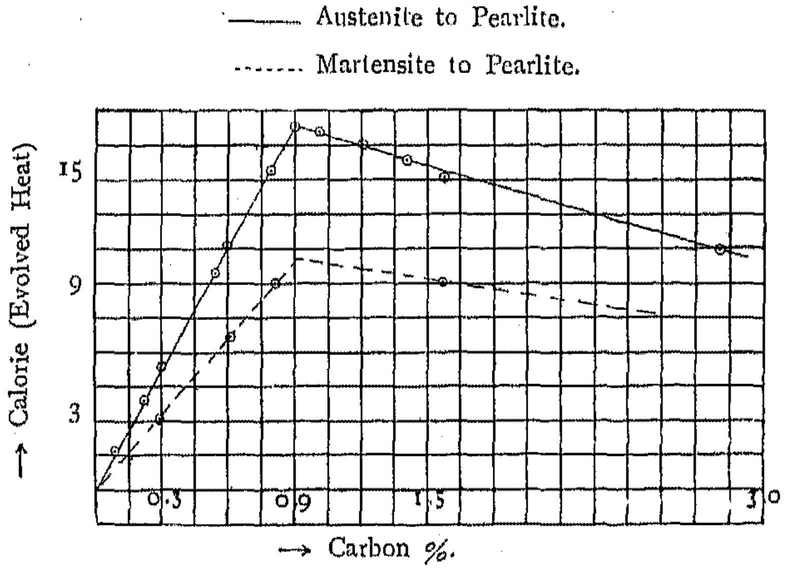
Austenite to Pearlite.



from the heat content above and below this transformation point, the heat of transformation from pearlite to austenite or from austenite to pearlite can be obtained (Fig. 11). The following table and Fig. 12 contain the results of measurement :—

C %	Aust. $\rightleftarrows$ Pearl.	C %	Aust. $\rightleftarrows$ Pearl.
0.09	1.6 calories	0.92	16.0 calories
0.224	4.0	0.994	15.7
0.30	5.3	1.24	15.2
0.54	9.6	1.41	14.5
0.61	10.8	1.575	13.6
0.795	14.1	2.84	10.7

Fig. 12.



As the above table shows, the quantity of heat required for the precipitation of pearlite from austenite is zero in pure iron, increases with the content of carbon, reaches a maximum at 0.9 percent and then gradually decreases with the further increase of carbon. The heat quantity-concentration curve consists of two straight lines, which intersect at a 0.9 percent content of carbon. This change in the heat evolved at the A_1 point is to be expected from the quantity of pearlite present in steels. From the above results it is concluded that 1 gr. of pearlite requires a quantity of heat of 16.1 calories to form austenite, and therefore, 1 gr. of carbon requires 1670 calories to dissolve in iron to form austenite; while A. Meuthen obtained 15.9 calories for the heat of precipitation of pearlite per gram. In the range of the A_2 point, no abrupt change of heat can be seen; but in Fig. 1, it is observable that in low carbon steels, the heat content-temperature curve is abnormally high above 600°C, indicating a gradual evolution of heat, due to the A_2 change during cooling.

(b). The nature of the A_1 and A_2 transformations.

The A_1 transformation is the process of dissolution or precipitation of cementite in iron; while, the A_2 transformation is, according to Prof. K. Honda,(1) not a change of phase, but a gradual change of energy in iron atoms themselves, beginning at the lowest temperature and ending in the vicinity of 790°C; this has been actually proved by his magnetic experiment.

The present writer undertook to show the difference of the thermal behaviours between these two changes, and examined 20 specimens of steel with a 0.80 % of carbon content, these specimens being 10 mm. in diameter and 30 mm. in length. Each specimen was placed in the furnace kept at 720°C and heated for different intervals of time. The specimen thus heated was let fall into the calorimeter and the mean specific heat was obtained from the quantity of heat given off to the calorimeter. For the A_2 transformation, the observation was also carried out in the same way as in the case of the A_1 transformation, keeping the temperature constant at 780°C. The results are as follows:—

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(1) Sci. Rep., 4, (1915), 169; Jour. Iron and Steel Inst., No. 1, (1915), 199.

Specific heat at A_1 and A_2 transformations (0.80 %C).

Heating time (minutes)	Sp. heat at 720°C	Sp. heat at 780°C	Heating time (minutes)	Sp. heat at 720°C	Sp. heat at 780°C
3	0.1563	0.1632	20	0.1650	0.1646
5	0.1605	0.1646	25	0.1668	0.1640
7	0.1630	0.1640	30	0.1652	0.1638
10	0.1658	0.1650	35	0.1664	0.1635
15	0.1656	0.1641	Mean	**0.1658**	**0.1642**

The above result shows that, the specimen requires about 15 minutes for the completion of the A_1 transformation, while it requires only 4~5 minutes for the A_2 transformation. It will be easily seen how great is the difference between the rates of the A_1 and the A_2 transformations, if the time during which the temperature of the specimen reaches that of the furnace, is taken into account. To get an idea of this time, an axial hole, 2 mm. in diameter, was bored to the centre of the specimen, into which a thermocouple was inserted, while another thermocouple was also held so as to touch the outside of the specimen. The specimen thus arranged was placed in the furnace, kept at 700°C or 900°C, after which the temperature readings of these thermocouples were taken. In this way, the time required for heating the specimen was determined with the result shown in the following table :—

Time (minutes)	At 700°C		At 900°C	
	Inside	Outside	Inside	Outside
1	631	675		
1.5			814	864
2.0	689	698	865	896
2.5			887	900
3.0	698	699	895	899
3.5			898	900
4.0	700	700	900	900
4.5			900	900
5.0	700	700	900	900
5.5			900	900
6.0			900	900
7.0	700	700		
10.0	700	700		

The above results show that the temperature takes about 4 minutes to penetrate from the surface to the centre of the specimen. From this fact, it is easily seen that for the completion of the A_1 transformation a certain time is required; while the A_2 transformation is completed almost at the same time as the temperature of the specimen attains the required value. This shows that the A_2 transformation is a function of temperature only but not of time as in the case of the A_1 transformation. Hence it is concluded that the A_2 transformation is of a quite different nature from that of the A_1 transformation. This fact has been already expressed by Prof. K. Honda⁽¹⁾ in his magnetic investigation and his result completely agrees with that given above.

VI (a). Specific heat above the A_3 point.

Above the A_3 point, the structure is entirely austenitic, and it is observed that the specific heat in this region remains constant in low carbon steels or slowly diminishes in high carbon steels. (See Figs. 1 and 2.)

Examined under the microscope, the structure of the specimen quenched from an austenitic region shows martensite. In the case of the hyper-eutectoid steel, it is also found by the X-ray analysis, that a small quantity of austenite still remains unchanged in the martensite. Hence due corrections corresponding to the heat of transformation from martensite to pearlite and to the heat of the untransformed austenite should be added to the observed specific heat. These quantities of heat to be added can be obtained by comparing it with the gradient of the heat content-concentration curves in Fig. 5, as explained below.

(b). Heat of transformation from martensite to pearlite.

The microstructure of steels corresponding to the heat content-concentration curves at 700°C and 850°C are respectively sorbitic and martensitic. Thus because of the formation of martensite, the direction

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(1) K. Honda, Sci. Rep., **5**, (1916), 285.

of the curve at 700°C changed to that of the curves above 850°C, as shown in Fig. 5; hence if in Fig. 5, we draw a straight line parallel to the line at 700°C through each point corresponding to pure iron lying above 850°C, the difference in the ordinates between these two lines at a given concentration gives the heat of transformation from martensite to pearlite.

The results of such calculation are given below :—

Heat of Transformation.

Temp. / C(%)	850°C	900°C	1000°C	1100°C	1200°C	1250°C
0.09	1.1	1.1	1.1	1.1	1.1	1.2
0.224	2.6	2.6	2.6	2.6	2.8	2.9
0.30	3.4	3.4	3.4	3.5	3.8	3.9
0.54	6.1	6.2	6.2	6.3	6.9	7.0
0.61	6.8	6.8	6.8	7.1	7.8	8.0
0.80	8.9	9.0	9.0	9.2	10.3	10.4
0.92	10.2	10.3	10.2	10.4	11.6	11.9
0.994	10.0	10.1	10.0	10.3	11.5	11.6
1.235	9.6	9.7	9.7	9.8	11.1	11.3
1.41	9.3	9.4	9.4	9.5	10.7	10.8
1.58	9.0	9.1	9.1	9.2	10.4	10.5
2.84	6.8	6.9	6.9	6.9	7.8	7.9

The fact that the heat of transformation from martensite to pearlite increases slightly with the rise of temperature is probably due to the quantity of austenite remaining unchanged in the martensite. Hence for eutectoid steel, the value of 10.2 calories is very probably the correct value for the heat of the transformation from martensite to pearlite per one gram of the steel. This is equivalent to saying that 1 gr. of carbon requires 1133 calories to be dissolved for the formation of martensite, or 1 gr. of cementite requires 75.9 calories to be dissolved in iron, or the molecular heat of dissolution of carbon or cementite is 13.6 kilo-calories. This value exactly coincides with that obtained by N. Yamada.⁽¹⁾

(c). Heat of transformation from austenite to martensite.

The heat of the A_1 transformation consists of the sum of the heat of the transformation from austenite to martensite and that from martensite to pearlite; hence the heat of transformation from austenite to martensite can be obtained from the heat of the A_1 transformation and that of the transformation from martensite to pearlite. Referring to a steel of 0.9 % carbon content, we find the following value for the latter heat of transformation :—

$$16.1 - 10.2 = 5.9 \ cal.$$

N. Yamada obtained a value of 5.6 calories for the same heat. By a similar calculation, we obtained the results shown in the following table :—

C (%)	Aust. $\rightleftarrows$ Mart.	C (%)	Aust. $\rightleftarrows$ Mart.
0.09	0.7 cal.	0.92	5.9 cal.
0.224	1.5	0.994	5.8
0.30	2.0	1.235	5.6
0.54	3.5	1.41	5.4
0.61	4.0	1.58	5.3
0.80	5.3	2.84	3.9
0.90	5.9		

From the above table and Fig. 12, we conclude that the heat of the transformation from austenite to martensite is proportional to the content of entectoid carbon, this indicating that martensite is a definite phase,⁽²⁾ but not an indefinite transforming substance.

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(1) l. c.

(2) K. Honda, Sci. Rep., 8, (1919), 181.

(d). A direct determination of the heat of transformation from martensite to pearlite.

The determination was carried out by the same method as Prof. K. Honda had already used. One of the specimens having the same composition and dimensions is covered with asbestos paper, and the other is not so covered. By letting each of these specimens fall into the calorimeter from a high temperature, the heat content was measured in the same way as before. In the former case, the structure after cooling was sorbitic, while in the latter, it was martensitic. The carbon contents of the specimens used in the experiment are 0.28 %, 0.61 %, 0.80 % and 1.58 % respectively. Of course, the effect of the asbestos paper on the heat content of the specimen was taken into consideration.

The results are given below and in Fig. 13.

0.28 % C.

Temp.	Covered	Not covered	Diff. (M ⇄ P)
850	145.4	142.2	3.2
900	153.6	150.4	3.2
1000	170.3	167.0	3.3
1100	187.6	184.2	3.4
1200	204.9	201.3	3.6
1250	213.4	209.5	3.9

0.61 % C.

Temp.	Covered	Not covered	Diff. (M ⇄ P)
800	137.5	130.8	6.7
850	146.4	139.6	6.8
900	154.2	147.3	6.9
1000	171.0	164.0	7.0
1100	188.0	180.9	7.1
1200	206.0	198.0	8.0
1250	214.8	206.9	7.9

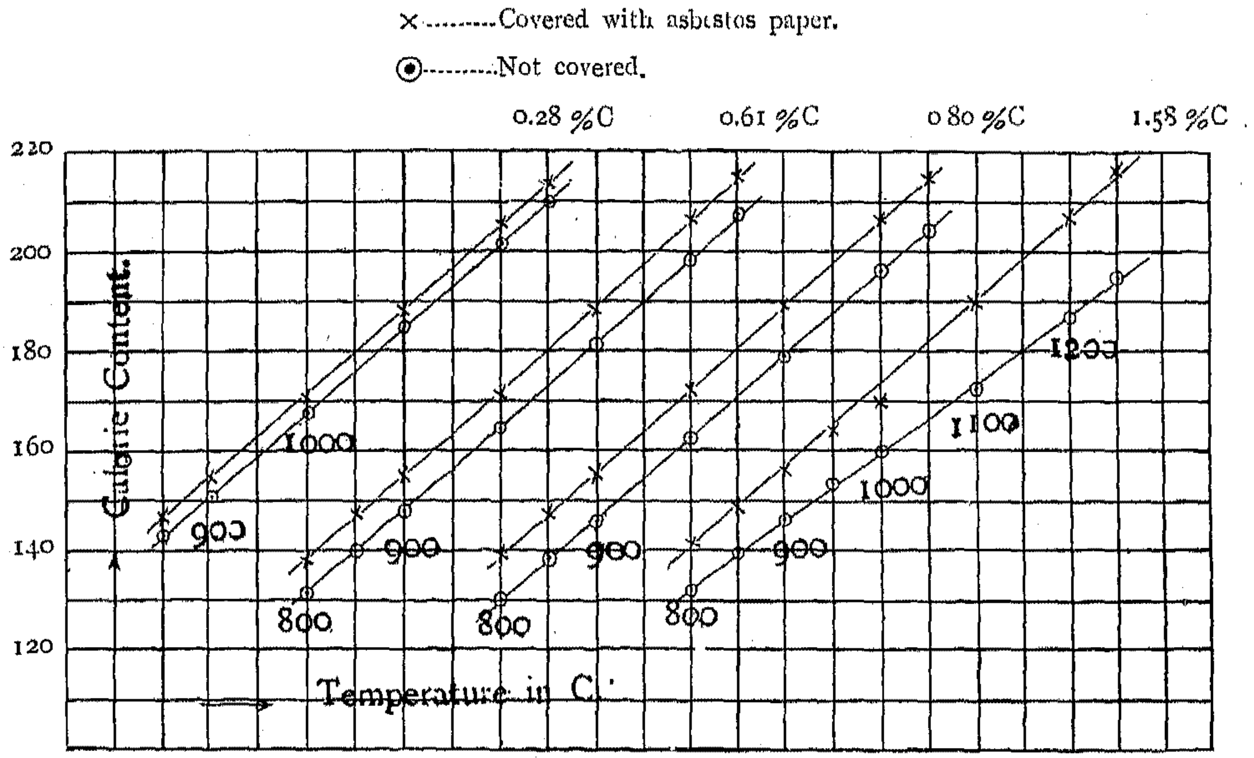
0.80 % C.

Temp.	Covered	Not covered	Diff. (M ⇄ P)
800	138.2	129.5	8.7
850	147.0	138.0	9.0
900	155.0	145.9	9.1
1000	171.4	162.2	9.2
1100	188.2	179.0	9.2
1200	206.4	196.1	10.3
1250	214.8	204.5	10.3

1.58 % C.

Temp.	Covered	Not covered	Diff. (M ⇄ P)
800	141.3	132.3	9.0
850	148.4	139.4	9.0
900	155.7	146.6	9.1
950	163.3	154.0	9.3
1000	169.6	160.0	9.6
1100	190.0	172.0	18.0
1200	207.0	187.0	20.0
1250	216.7	195.3	21.4

Fig. 13.



From Fig. 13, it will be seen that in low carbon steels, the heat content-temperature curves for covered and uncovered specimens run nearly parallel to each other, but in high carbon steels, these two lines diverge from each other, as the temperature rises. This is due to the fact that, in high carbon steels, a small quantity of austenite is present mixed in the martensite, its amount increasing with the rise of temperature. Hence in these steels, the correct values of the heat of transformation from martensite to pearlite are those found in the range of temperatures 800~850°C. They are also included in Fig. 12; this result completely agrees with that mentioned in the last section.

(e). Mean specific heat above the A_1 point.

Above the A_1 point, if the temperature is comparatively low, that is, below 800°C, the specimen let fall into the calorimeter shows the martensitic structure mixed with troostite, but as the temperature rises, the rate of cooling rapidly increases and the structure becomes purely martensitic. With a further increase of temperature, say above 850°C, the martensitic structure becomes mixed with a small quantity of austenite. Accordingly, the heat content above the A_1 point, as shown in Fig. 5, does not represent the true heat content at the same temperature. The observed heat is the sum of the specific heat up to the said temperature increased by the heat of transformation from austenite to martensite, and hence is less than the true heat content by the heat of transformation from martensite to pearlite. Hence in order to find the true heat content above the A_1 point, a correction for the heat of transformation from martensite to pearlite must be added to the observed values given in Figs. 1 and 2. Since this heat of transformation is proportional to the carbon content as shown in Fig. 12, the correction can easily be made. In Fig. 5, the heat content-concentration curves in the range 700~850°C, is not straight throughout, but is curved in parts; the fact that the initial portion of these curves rises linearly with the content of carbon up to 0.2~0.9 percent, indicates the presence of troostite mixed with martensite.

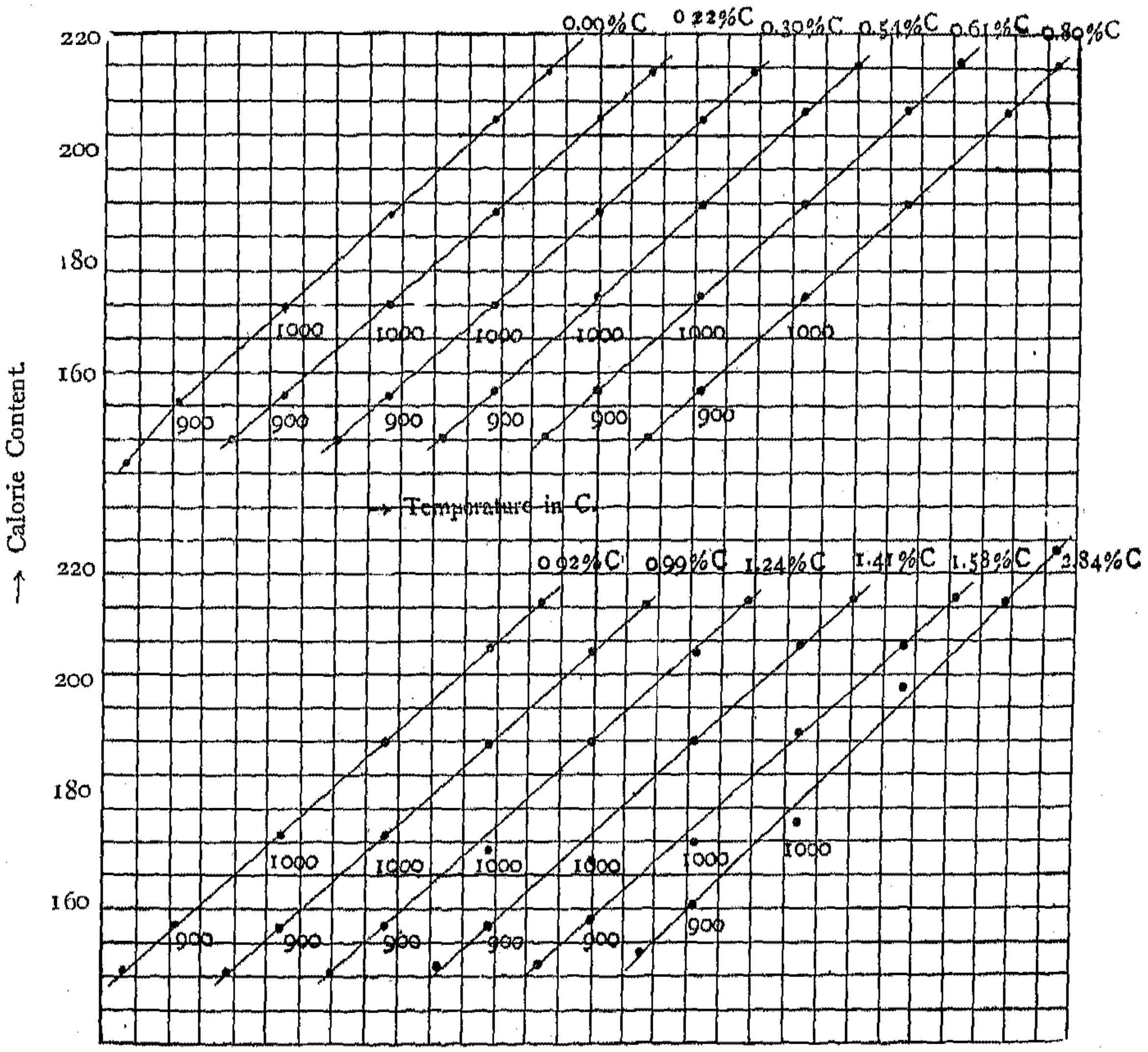
As the temperature rises the straight portion of the curves diminishes, showing that the quantity of troostite decreases and that of martensite increases. This was also actually confirmed by microscopic examination. Above 850°C, the straight portion of the curves shows a break changing its direction downwards to one upwards; this break takes place at a higher concentration as the temperature rises. This is understood from the form of the solubility curve of cementite in iron, and the increase of heat content at higher concentration is due to an increasing amount of free cementite in hyper-eutectoid steels.

Thus with the increase of carbon content, the temperature giving rise to a pure martensitic structure falls, and above a 0.54 percent content of carbon, every specimen shows almost the structure of pure martensite from 800°C upwards, while below this percentage, the above structure is first formed from 850 or 900°C upwards. On the other hand, the specimens quenched in water from the region in which the linear increase of the heat content curve was observable, showed a pure martensitic structure.

If we find the quantity of heat evolved in the course of the transformation from martensite to pearlite from the results shown in Figs. 12 and 13, and combine it with the results shown in Figs. 1 and 2, we obtain the true heat content above the A_1 point, as shown in Fig. 14.

Fig. 14.

True Heat Content above 850°C.



Calculating the value of the mean specific heat from these results, we find that, within the range up to 1250°C, the value is almost independent of the carbon content in both hypo-and hyper-eutectoid steels, as shown in the following tables. Thus A. Meuthen's conclusion, that is, that the true specific heat is independent of temperature, is valid above the A_1 point.

0.09 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	140.4	141.5	0.1650	0.1666
900	152.3	153.4	0.1691	0.1704
1000	168.9	170.0	0.1689	0.1700
1100	186.0	187.1	0.1689	0.1701
1200	203.1	204.2	0.1690	0.1703
1250	211.5	212.7	0.1691	0.1701

0.224 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	142.5	145.1	0.1678	0.1707
900	150.8	153.4	0.1678	0.1704
1000	167.6	170.2	0.1676	0.1702
1100	184.5	187.1	0.1678	0.1703
1200	201.7	204.5	0.1693	0.1705
1250	210.2	213.1	0.1685	0.1706

0.30 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	142.1	145.5	0.1673	0.1710
900	150.0	153.4	0.1668	0.1705
1000	166.9	170.3	0.1669	0.1703
1100	183.8	187.3	0.1670	0.1703
1200	201.0	204.8	0.1676	0.1701
1250	209.6	213.5	0.1674	0.1708

0.54 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp heat (obs.)	Mean sp. heat (corr.)
850	140.0	146.1	0.1648	0.1768
900	148.1	154.3	0.1647	0.1713
1000	164.6	170.8	0.1646	0.1708
1100	181.7	188.0	0.1650	0.1709
1200	198.6	205.5	0.1657	0.1714
1250	207.5	214.5	0.1660	0.1718

0.61 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	139.6	146.4	0.1644	0.1723
900	147.3	154.1	0.1639	0.1713
1000	164.0	170.8	0.1640	0.1708
1100	180.9	188.0	0.1645	0.1709
1200	198.0	205.8	0.1650	0.1715
1250	206.9	214.9	0.1657	0.1720

0.795 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	138.0	146.9	0.1624	0.1726
900	145.9	154.9	0.1620	0.1720
1000	162.2	171.2	0.1622	0.1712
1100	179.0	188.2	0.1629	0.1710
1200	196.1	206.4	0.1635	0.1719
1250	204.5	214.9	0.1638	0.1720

0.92 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	137.0	147.1	0.1612	0.1730
900	144.7	154.0	0.1607	0.1710
1000	160.8	171.2	0.1608	0.1712
1100	177.9	188.5	0.1616	0.1713
1200	194.2	205.7	0.1618	0.1714
1250	202.9	214.9	0.1620	0.1720

0.994 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	136.2	146.2	0.1604	0.1720
900	144.5	154.6	0.1606	0.1717
1000	160.2	171.6	0.1602	0.1716
1100	177.0	188.6	0.1611	0.1716
1200	192.1	204.6	0.1600	0.1706
1250	201.2	214.3	0.1610	9.1715

1.235 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	136.2	145.8	0.1604	0.1715
900	144.0	152.7	0.1600	0.1708
1000	157.9	167.6	0.1579	0.1676
1100	174.9	189.2	0.1590	0.1724
1200	19.00	205.5	0.1584	0.1713
1250	199.0	215.2	0.1592	0.1722

1.41 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	138.0	147.3	6.1625	6.1733
900	144.0	153.4	0.1600	0.1704
1000	156.1	165.5	0.1561	0.1655
1100	173.1	189.4	0.1575	0.1722
1200	189.0	206.6	0.1575	0.1722
1250	197.0	215.5	0.1577	0.1724

1.575 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	139.4	148.4	0.1640	0.1746
900	146.6	155.7	0.1630	0.1730
1000	160.0	169.6	0.1600	0.1696
1100	173.5	191.7	0.1578	0.1743
1200	187.0	206.8	0.1559	0.1725
1250	195.3	216.0	0.1564	0.1728

2.84 % C.

Temp.	Total calorie (obs.)	Total calorie (corr.)	Mean sp. heat (obs.)	Mean sp. heat (corr.)
850	140.3	149.8	0.1651	0.1757
900	148.2	157.9	0.1649	0.1753
1000	164.4	173.0	0.1644	0.1730
1100	175.0	200.0	0.1590	0.1817
1200	187.1	213.1	0.1560	0.1776
1250	192.5	224.5	0.1542	0.1796

§ 5. CONCLUSION.

The results of the present investigation may be summarized as follows :—

(1) The heat content of carbon steels at high temperatures was determined by the mixture method, while the oxidation of the specimen was prevented by passing a purified hydrogen gas through the furnace. The specimens were twelve kinds of steels with different carbon contents from 0.09 % to 2.84 % and the range of temperature was 23∼1250°C.

(2) According to A. Meuthen, the specific heat is constant below the A_1 point, but the present writer showed that the specific heat is only constant above the A_3 point, and that below this point, it increases with the rise of temperature.

(3) The quantity of heat for the dissolution of pearlite in iron was determined by measuring the heat content above and below the A_1 point. This heat increases proportionally with the content of carbon, reaches a maximum at 0.9 percent and ends at 6.7 percent.

For the dissolution of 1 gr. of carbon in iron, a heat of 1760 calories is required, while, 16.1 calories are necessary for the dissolution of 1 gr. of pearlite in iron.

(4) From the heat content-concentration curve, it was found that, the means pecific heat of cementite increases with the rise of temperature ; it is 0.149 at 150°C and 02.20 at 850°C.

(5) It was observed that the specific heat of the carbon poles with 98 %C increases almost linearly up to 700°C, and afterwards its rate of increase gradually diminishes.

(6) It is confirmed by experiments that the A_1 transformation is a function of temperature and time, but that the A_2 transformation is a definite function of temperature only.

(7) From the heat content-concentration curves, the heat of transformation from martensite to pearlite was obtained and found to be proportional to the carbon content.

(8) The heat of transformation from austenite to martensite, or

that from martensite to pearlite, increases proportionally with the content of eutectoid carbon. The heat of transformation from austenite to martensite for a eutectoid steel amounts to 5.9 calories.

In conclution, I wish to express my hearty thanks to Professor K. Honda for his kind guidance, and the same gratitude should be expressed to Professor T. Hayashi, who always encouraged me during my investigation. While, I am also greatly indebted to those assistants, viz. Messrs. T. Nakahata, F. Fukuda, K. Nagata, H. Aoyagi, M. Seto, M. Mihirota, T. Tsukada and H. Nagafuji, by whose zealous efforts the present investigation was satisfactorily carried out.

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This numerical tables are to be inserted to
the end of the paper :—

"On the Specific Heat of Carbon Steels,"

Sci. Rep. Vol. XV. No. 3, p. 331.

Appendix: Observed Data.

$$C = \frac{(W+w)\ (t_2-t_0)}{m\ (t_1-t_2)}$$

here $W=500.0$ gr. and $w=25.0$ gr.,

0.09 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=7.961$ gr.; $t_1=100°$.			$m=8.105$ gr.; $t_1=200°$.		
23.112	23.240	0.1100	23.001	23.312	0.1141
23.015	23.145	0.1110	23.012	23.321	0.1138
22.990	23.118	0.1104	23.056	23.366	0.1137
23.103	23.234	0.1115	22.950	23.262	0.1144
23.007	23.137	0.1112			
		Mean 0.1108			Mean 0.1140
$m=8.125$ gr.; $t_1=300°$.			$m=8.007$ gr.; $t_1=400°$.		
23.002	23.507	0.1180	23.010	23.713	0.1225
23.015	23.519	0.1178	22.980	23.681	0.1221
23.101	23.606	0.1184	22.994	23.710	0.1228
		Mean 0.1181			Mean 0.1225
$m=7.751$ gr.; $t_1=500°$.			$m=6.997$ gr.; $t_1=600°$.		
22.987	23.897	0.1267	23.002	24.019	0.1350
23.011	23.904	0.1270	22.975	23.995	0.1354
23.106	23.997	0.1268	22.980	24.013	0.1346
		Mean 0.1268			Mean 0.1350
$m=9.125$ gr.; $t_1=700°$.			$m=8.721$ gr.; $t_1=710°$.		
23.100	24.778	0.1430	22.886	24.526	0.1440
23.105	24.777	0.1425	22.874	24.508	0.1435
23.109	24.793	0.1435	22.984	24.632	0.1448
		Mean 0.1430			Mean 0.1441
$m=8.322$ gr.; $t_1=730°$.			$m=7.607$ gr.; $t_1=750°$.		
23.102	24.757	0.1480	22.875	24.452	0.1500
23.113	24.772	0.1484	22.912	24.496	0.1507
23.121	24.782	0.1486	22.923	24.505	0.1505
23.157	24.807	0.1476			
		Mean 0.1482			Mean 0.1504
$m=7.923$ gr.; $t_1=770°$.			$m=8.010$ gr.; $t_1=800°$.		
23.012	24.733	0.1530	22.987	24.866	0.1589
23.102	24.827	0.1534	22.992	24.876	0.1593
			23.101	24.972	0.1582
		Mean 0.1532			Mean 0.1588
$m=7.731$ gr.; $t_1=850°$.			$m=7.716$ gr.; $t_1=900°$.		
23.001	25.006	0.1650	22.81	24.99	0.1694
23.103	25.101	0.1645	22.87	25.04	0.1690
23.077	25.087	0.1655	22.89	25.06	0.1688
		Mean 0.1650			Mean 0.1691

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=7.812 gr.; t_1=1000°.			m=8.227 gr.; t_1=1100°.		
22.91	25.36	0.1688	23.10	25.94	0.1687
22.90	25.35	0.1690	22.20	26.05	0.1691
23.10	25.55	0.1689			
		Mean 0.1689			Mean 0.1689
m=8.323 gr.; t_1=1200°.			m=8.440 gr.; t_1=1250°.		
23.10	26.24	0.1687	23.10	26.43	0.1693
23.10	26.24	0.1689	23.00	26.32	0.1689
23.00	26.15	0.1694			
		Mean 0.1690			Mean 0.1691

0.224 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=7.926 gr.; t_1=100°.			m=7.818 gr.; t_1=200°.		
23.125	23.254	0.1112	22.834	23.135	0.1140
23.100	23.229	0.1114	22.893	23.194	0.1146
23.107	23.237	0.1117	22.912	23.213	0.1143
22.914	23.042	0.1109			
		Mean 0.1113			Mean 0.1143
m=7.881 gr.; t_1=300°.			m=7.652 gr; t_1=400°.		
22.974	23.469	0.1192	22.516	23.190	0.1227
22.968	23.464	0.1194	22.617	23.293	0.1231
		Mean 0.1193			Mean 0.1229
m=8.227 gr.; t_1=500°.			m=8.100 gr.; t_1=600°.		
22.724	23.672	0.1270	23.001	24.201	0.1351
23.006	23.958	0.1276	23.203	24.408	0.1357
23.102	24.051	0.1273	23.401	24.603	0.1354
		Mean 0.1273			Mean 0.1354
m=7.972 gr.; t_1=700°.			m=7.883 gr.; t_1=710°.		
23.012	24.479	0.1430	23.202	24.681	0.1437
23.109	24.580	0.1434	23.105	24.592	0.1445
			23.202	24.685	0.1441
		Mean 0.1432			Mean 0.1441
m=7.772 gr.; t_1=730°.			m=7.967 gr.; t_1=750°.		
23.101	24.692	0.1524	23.208	24.906	0.1543
23.105	24.688	0.1516	23.628	25.318	0.1537
		Mean 0.1520			Mean 0.1540
m=8.218 gr.; t_1=770°.			m=8.103 gr.; t_1=800°.		
22.562	24.383	0.1560	22.816	24.751	0.1617
22.661	24.490	0.1567	22.712	24.654	0.1623
22.712	24.530	0.1558			
22.725	24.540	0.1555			
		Mean 0.1560			Mean 0.1620

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=8.345 gr.; t_1=850°.			m=6.565 gr.; t_1=900°.		
22.810	25 009	0.1677	22.67	24.506	0.1677
m=6.752 gr..			22.54	24.378	0.1679
23.12	24.905	0.1682			
23.03	24.808	0.1675			
		Mean 0.1678			Mean 0.1678
m=7.120 gr.; t_1=1000°.			m=6.412 gr.; t_1=1100°.		
21.87	24.09	0.1675	22.05	24.25	0.1678
21.96	24.18	0.1678	21.56	23.75	0.1669
22.06	24.29	0.1674	21.32	23.53	0.1681
m=7.412 gr..					
22.01	24.32	0.1676			
		Mean 0.1676			Mean 0.1676
m=6.135 gr.; t_1=1200°.			m=6.727 gr.; t_1=1250°.		
21.03	23.36	0.1697	20.37	23.01	0.1682
20.21	22.56	0.1691	20.22	22.87	0.1688
20.12	22.44	0.1689	20.06	22.71	0.1685
21.11	23.44	0.1695			
		Mean 0.1693			Mean 0.1685

0.30 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=7.861 gr.; t_1=100°.			m=8.222 gr.; t_1=200°.		
23.322	23.449	0.1114	23.125	23.444	0.1152
23.102	23.230	0.1116	23.020	23.337	0.1146
23.004	23.131	0.1110	22.877	23.194	0.1146
22.899	23.028	0.1120			
		Mean 0.1113			Mean 0.1148
m=8.423 gr.; t_1=300°.			m=7.627 gr.; t_1=400°.		
23.718	24.251	0.1205	23.210	23.882	0.1230
23.432	23.963	0.1198	23.012	23.690	0.1241
22.765	23.296	0.1197	23.004	23.675	0.1228
		Mean 0.1200			Mean 0.1233
m=7.892 gr.; t_1=500°.			m=8.765 gr.; t_1=600°.		
23.124	24.036	0.1275	22.787	24.089	0.1354
22.887	23.804	0.1281	22.456	23.764	0.1360
22.645	23.560	0.1278	22.421	23.726	0.1356
		Mean 0.1278			Mean 0.1355
m=9.104 gr.; t_1=700°.			m=11.220 gr.; t_1=710°.		
21.993	23.673	0.1433	22.463	24.594	0.1440
22.102	23.787	0.1437	23.107	25.223	0.1446
22.123	23.809	0.1438			
		Mean 0.1436			Mean 0.1443

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=6.352$ gr.; $t_1=730^\circ$.			$m=10.105$ gr.; $t_1=750^\circ$.		
22.232	23.551	0.1543	21.124	23.292	0.1550
22.476	23.789	0.1537	21.131	23.316	0.1562
$m=8.651$ gr..			23.100	24.490	0.1553
21.876	23.663	0.1535			
22.536	24.333	0.1545			
		Mean 0.1540			Mean 0.1555
$m=8.482$ gr.; $t_1=770^\circ$.			$m=9.135$ gr.; $t_1=800^\circ$.		
22.009	23.908	0.1575	21.465	23.686	0.1644
$m=6.762$ gr..			22.378	24.601	0.1648
22.104	23.623	0.1580	23.010	25.230	0.1647
21.765	23.284	0.1579	21.497	23.719	0.1645
		Mean 0.1578			Mean 0.1646
$m=8.905$ gr.; $t_1=850^\circ$.			$m=6.327$ gr.; $t_1=900^\circ$.		
22.476	24.813	0.1670	22.102	23.860	0.1665
21.864	24.212	0.1676	21.92	23.685	0.1671
21.642	23.986	0.1673	22.34	24.10	0.1668
		Mean 0.1673			Mean 0.1668
$m=7.641$ gr.: $t_1=1000^\circ$.			$m=8.134$ gr.; $t_1=1100^\circ$.		
22.12	24.49	0.1666	21.64	24.43	0.1672
22.01	24.38	0.1668	22.107	24.894	0.1673
21.97	24.35	0.1673	21.60	24.38	0.1668
			21.07	23.85	0.1667
		Mean 0.1669			Mean 0.1670
$m=8.432$ gr.; $t_1=1200^\circ$.			$m=6.756$ gr.; $t_1=1250^\circ$.		
21.32	24.48	0.1673	21.00	23.64	0.1676
$m=7.652$ gr..			22.13	24.77	0.1672
21.02	23.90	0.1679			
21.05	23.92	0.1676			
		Mean 0.1676			Mean 0.1674

0.54 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=9.254$ gr.; $t_1=100^\circ$.			$m=9.254$ gr.; $t_1=200^\circ$.		
23.104	23.256	0.1122	23.254	23.613	0.1154
23.007	23.160	0.1128	23.017	23.374	0.1146
23.127	23.280	0.1130	23.206	23.563	0.1147
22.895	23.047	0.1120			
		Mean 0.1125			Mean 0.1149
$m=8.724$ gr.; $t_1=300^\circ$.			$m=8.216$ gr.; $t_1=400^\circ$.		
23.108	23.663	0.1208	23.107	23.837	0.1245
23.009	23.565	0.1211	22.005	22.744	0.1251
23.004	23.556	0.1202	22 908	23.643	0.1248
		Mean 0.1207			Mean 0.1248

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=7.625 gr.; $t_1=500°$.			m=10.102 gr.; $t_1=600°$.		
22.765	23.650	0.1279	22.463	23.975	0.1364
22.864	23.751	0.1283	22.345	23.853	0.1360
22.777	23.665	0.1284	22.121	23.627	0.1358
		Mean 0.1282			Mean 0.1361
m=11.201 gr.; $t_1=700°$.			m=9.210 gr.; $t_1=710°$.		
22.346	24.430	0.1446	22.768	24.509	0.1448
23.011	25.085	0.1440	23.815	25.556	0.1450
23.102	25.180	0.1443	21.893	23.645	0.1455
		Mean 0.1443			Mean 0.1451
m=8.178 gr.; $t_1=730°$.			m=6.798 gr.; $t_1=750°$.		
21.468	23.240	0.1610	21.642	23.159	0.1612
21.246	22.999	0.1592	22.106	23.628	0.1618
21.343	23.093	0.1589	23.602	25.118	0.1615
21.109	22.859	0.1589			
		Mean 0.1595			Mean 0.1615
m=8.414 gr., $t_1=770°$.			m=8.109 gr.; $t_1=800°$.		
21.881	23.828	0.1628	21.42	23.387	0.1640
21.872	23.819	0.1628	21.37	23.348	0.1649
21.436	23.391	0.1634	21.52	23.495	0.1647
			21.48	23.452	0.1644
		Mean 0.1630			Mean 0.1645
m=10.025 gr.; $t_1=850°$.			m=7.643 gr.; $t_1=900°$.		
21.21	23.805	0.1645	20.91	23.014	0.1648
22.30	24.901	0.1651	21.42	23.510	0.1641
22.04	24.637	0.1648	20.82	22.929	0.1652
		Mean 0.1648			Mean 0.1647
m=8.515 gr.; $t_1=1000°$.			m=7.862 gr.; $t_1=1100°$.		
21.23	23.83	0.1642	21.04	23.69	0.1647
21.37	24.00	0.1649	21.08	23.74	0.1653
21.40	24.02	0.1653			
21.42	24.16	0.1640			
		Mean 0.1646			Mean 0.1650
m=9.146 gr.; $t_1=1200°$.			m=6.208 gr.; $t_1=1250°$.		
21.11	24.51	0.1658	21.04	23.46	0.1666
21.16	24.53	0.1656	22.07	24.47	0.1654
			20.09	22.50	0.1659
		Mean 0.1657			Mean 0.1660

0.61 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=11.256 gr.; $t_1=100°$.			m=11.256 gr.; $t_1=200°$.		
22.813	23.001	0.1142	22.509	22.945	0.1154
22.910	23.097	0.1137	22.716	23.154	0.1160
23.003	23.193	0.1146	22.918	23.355	0.1157
23.102	23.289	0.1143			
		Mean 0.1142			Mean 0.1157

t_0	t_2	M.s.h.
m = 12.026 gr.; t_1 = 300°.		
23.012	23.781	0.1215
23.005	23.773	0.1214
22.643	23.417	0.1222
		Mean 0.1217
m = 10.862 gr.; t_1 = 400°.		
22.521	23.495	0.1250
23.412	24.388	0.1256
23.024	23.999	0.1253
		Mean 0.1253
m = 9.612 gr.; t_1 = 500°.		
23.246	24.365	0.1285
23.347	24.461	0.1279
23.412	24.534	0.1289
22.610	23.736	0.1291
		Mean 0.1286
m = 8.787 gr.; t_1 = 600°.		
22.310	23.628	0.1366
22.102	23.426	0.1372
22.346	23.664	0.1366
		Mean 0.1368
m = 8.621 gr.; t_1 = 700°.		
22.415	24.015	0.1441
21.321	22.935	0.1452
21.645	23.251	0.1445
		Mean 0.1446
m = 9.101 gr.; t_1 = 710°.		
22.412	24.141	0.1452
22.501	24.233	0.1457
22.406	24.134	0.1453
		Mean 0.1454
m = 7.633 gr.; t_1 = 730°.		
21.325	22.983	0.1613
21.412	23.074	0.1617
		Mean 0.1615
m = 8.304 gr.; t_1 = 750°.		
22.346	24.211	0.1625
23.010	24.878	0.1629
		Mean 0.1631
m = 8.632 gr; t_1 = 770°.		
22.059	24.065	0.1636
22.502	24.516	0.1643
22.410	24.418	0.1638
		Mean 0.1639
m = 7.412 gr.; t_1 = 800°.		
21.345	23.144	0.1640
21.444	23.234	0.1632
21.478	23.272	0.1636
		Mean 0.1636
m = 8.103 gr.; t_1 = 850°.		
21.526	23.620	0.1642
21.627	23.727	0.1647
21.068	23.165	0.1643
		Mean 0.1644
m = 7.102 gr.; t_1 = 900°.		
22.31	24.25	0.1636
23.00	24.95	0.1644
22.50	24.44	0.1637
22.78	24.72	0.1639
		Mean 0.1639
m = 6.812 gr.; t_1 = 1000°.		
21.47	23.55	0.1638
21.51	23.59	0.1642
		Mean 0.1640
m = 6.732 gr.; t_1 = 1100°.		
21.67	23.94	0.1644
21.82	24.09	0.1646
		Mean 0.1645
m = 7.108 gr.; t_1 = 1200°.		
22.00	24.63	0.1651
22.03	24.66	0.1652
22.11	24.73	0.1647
		Mean 0.1650
m = 8.106 gr.; t_1 = 1250°.		
21.24	24.36	0.1650
22.10	25.25	0.1664
		Mean 0.1657

0.795 % Carbon Steel.

t_0	t_2	M.s.h.
m = 13.165 gr.; t_1 = 100°.		
22.891	23.113	0.1150
22.911	23.134	0.1157
22.764	22.987	0.1154
22.675	22.897	0.1151
		Mean 0.1153
m = 13.165 gr.; t_1 = 200°.		
23.001	23.516	0.1163
22.986	23.498	0.1156
22.879	23.393	0.1161
		Mean 0.1160

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=12.140$ gr.; $t_1=300^\circ$.			$m=11.258$ gr.; $t_1=400^\circ$.		
22.641	23.430	0.1233	23.140	24.150	0.1253
22.532	23.312	0.1228	23.247	24.261	0.1259
23.012	23.797	0.1229	23.341	24.350	0.1253
		Mean 0.1230			Mean 0.1255
$m=11.258$ gr.; $t_1=500^\circ$.			$m=10.811$ gr.; $t_1=600^\circ$.		
22.643	23.961	0.1291	22.216	23.846	0.1374
22.542	23.896	0.1300	22.329	23.954	0.1370
22.447	23.781	0.1306	$m=10.812$ gr.,		
22.326	23.649	0.1295	23.014	24.643	0.1375
		Mean 0.1298			Mean 0.1373
$m=9.028$ gr.; $t_1=700^\circ$.			$m=9.028$ gr.; $t_1=710^\circ$.		
22.414	24.095	0.1445	22.307	24.020	0.1452
22.506	24.195	0.1453	22.105	23.835	0.1466
		Mean 0.1450			Mean 0.1459
$m=8.917$ gr.; $t_1=730^\circ$.			$m=8.343$ gr.; $t_1=750^\circ$.		
21.312	23.293	0.1650	21.347	23.248	0.1645
21.456	23.445	0.1657	20.987	23.894	0.1650
21.568	23.550	0.1652			
		Mean 0.1653			Mean 0.1648
$m=13.101$ gr.; $t_1=770^\circ$.			$m=7.645$ gr.; $t_1=800^\circ$.		
21.500	24.554	0.1642	22.012	23.837	0.1615
$m=8.790$ gr.,			22.004	23.833	0.1618
21.601	23.644	0.1635	22.015	23.854	0.1627
21.703	23.758	0.1643			
		Mean 0.1640			Mean 0.1620
$m=8.637$ gr.; $t_1=850^\circ$.			$m=9.042$ gr.; $t_1=900^\circ$.		
21.762	23.963	0.1620	21.42	23.86	0.1617
21.653	23.868	0.1630	21.31	23.76	0.1623
21.347	23.552	0.1622			
		Mean 0.1624			Mean 0.1620
$m=8.310$ gr.; $t_1=1000^\circ$.			$m=7.729$ gr.; $t_1=1100^\circ$.		
21.24	23.75	0.1625	21.63	24.21	0.1627
21.56	24.06	0.1618	21.91	24.49	0.1631
21.78	23.69	0.1623	22.03	24.61	0.1629
		Mean 0.1622			Mean 0.1629
$m=6.712$ gr.; $t_1=1200^\circ$.			$m=7.634$ gr; $t_1=1250^\circ$.		
21.26	23.71	0.1631	21.04	23.948	0.1631
21.37	23.83	0.1636	21.25	24.182	0.1645
21.57	24.03	0.1638			
		Mean 0.1635			Mean 0.1638

0.92 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=13.105$ gr.; $t_1=100^\circ$.			$m=11.023$ gr.; $t_1=200^\circ$.		
23.013	23.235	0.1162	22.881	23.318	0.1177
23.077	23.298	0.1157	23.001	23.439	0.1181
23.101	23.323	0.1160	23.010	23.448	0.1182
22.987	23.209	0.1157			
		Mean 0.1159			Mean 0.1180

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 13.401 gr.; t_1 = 300°.			m = 11.205 gr.; t_1 = 400°.		
23.101	23.966	0.1228	23.017	24.021	0.1251
22.897	23.765	0.1231	23.056	24.065	0.1258
22.911	23.779	0.1231	23.103	24.113	0.1259
		Mean 0.1230			Mean 0.1256
m = 10.328 gr.: t_1 = 500°.			m = 9.217 gr.; t_1 = 600°.		
22.018	23.243	0.1306	23.012	24.393	0.1367
22.346	23.563	0.1298	23.108	24.500	0.1378
22.465	23.682	0.1299	22.886	24.281	0.1380
		Mean 0.1301			Mean 0.1375
m = 8.121 gr.; t_1 = 700°.			m = 8.010 gr.; t_1 = 710°.		
21.992	23.514	0.1454	22.013	23.541	0.1459
22.108	23.623	0.1448	22.076	23.608	0.1463
22.201	23.719	0.1451			
		Mean 0.1451			Mean 0.1461
m = 8.010 gr.: t_1 = 730°.			m = 7.217 gr.; t_1 = 750°.		
22.103	23.902	0.1670	21.312	22.962	0.1651
22.108	23.914	0.1676	22.017	23.675	0.1661
21.765	23.567	0.1672			
21.425	23.234	0.1678			
		Mean 0.1674			Mean 0.1656
m = 7.217 gr.; t_1 = 770°.			m = 11.263 gr.; t_1 = 800°.		
22.108	23.790	0.1640	21.313	24.022	0.1627
22.201	23.891	0.1648	21.506	24.209	0.1624
			21.910	24.612	0.1624
		Mean 0.1644			Mean 0.1625
m = 10.201 gr.; t_1 = 850°.			m = 8.519 gr.: t_1 = 900°.		
22.301	24.887	0.1613	21.10	23.383	0.1605
22.405	24.982	0.1608	21.23	23.52	0.1610
23.108	25.695	0.1615	21 30	23.58	0.1606
		Mean 0.1612			Mean 0.1607
m = 10.204 gr.; t_1 = 1000°.			m = 11.806 gr.; t_1 = 1100°.		
22.03	25.07	0.1604	21.30	25.20	0.1612
21.64	24.70	0.1612	21.20	25.11	0.1618
			20.98	24.89	0.1618
		Mean 0.1608			Mean 0.1616
m = 7.923 gr.; t_1 = 1200°.			m = 7.651 gr.; t_1 = 1250°.		
20.86	23.73	0.1616	21.12	24.03	0.1626
20.79	23.67	0.1621	21.34	24.23	0.1615
21.65	24.52	0.1617	21.57	24.46	0.1619
		Mean 0.1618			Mean 0.1620

0.994 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 14.012 gr.; t_1 = 100°.			m = 14.012 gr.; t_1 = 200°.		
23.007	23.244	0.1158	23.106	23.663	0.1183
22.892	23.130	0.1161	23.007	23.567	0.1190
22.676	22.916	0.1167	22.768	23.325	0.1182
		Mean 0.1162			Mean 0.1185

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 12.451 gr.; t_1 = 300°.			m = 12.451 gr.; t_1 = 400°.		
22.881	23.688	0.1232	22.716	23.838	0.1258
23.013	23.819	0.1227	22.643	23.771	0.1264
23.004	23.810	0.1231	22.421	23.535	0.1258
		Mean 0.1230			Mean 0.1260
m = 13.123 gr.; t_1 = 500°.			m = 13.421 gr.; t_1 = 600°.		
22.312	23.864	0.1304	22.543	24.567	0.1376
22.365	23.908	0.1297	22.416	24.454	0.1385
23.010	24.554	0.1299	m = 7.651 gr..		
			22.508	23.668	0.1381
			22.101	23.259	0.1378
		Mean 0.1300			Mean 0.1380
m = 7.651 gr.; t_1 = 700°.			m = 9.617 gr.; t_1 = 710°.		
23.020	24.450	0.1453	22.641	24.481	0.1465
23.001	24.437	0.1459	22.342	24.177	0.1461
		Mean 0.1456			Mean 0.1463
m = 8.101 gr.; t_1 = 730°.			m = 7.655 gr.; t_1 = 750°.		
22.616	24.432	0.1668	23.102	24.843	0.1647
21.992	23.814	0.1672	23.008	24.762	0.1659
22.417	24.239	0.1673			
		Mean 0.1671			Mean 0.1653
m = 8.432 gr.; t_1 = 770°.			m = 7.412 gr.; t_1 = 800°.		
22.465	24.430	0.1641	22.123	23.898	0.1620
22.345	24.322	0.1651	22.457	24.242	0.1630
21.658	24.631	0.1646	22.137	23.910	0.1618
			22.020	23.808	0.1632
		Mean 0.1646			Mean 0.1625
m = 9.652 gr.; t_1 = 850°.			m = 9.144 gr.; t_1 = 900°.		
22.101	24.529	0.1600	21.24	23.687	0.1603
22.402	24.844	0.1610	21.34	23.800	0.1612
22.503	24.932	0.1602	21.57	24.016	0.1603
		Mean 0.1604			Mean 0.1606
m = 8.642 gr.; t_1 = 1000°.			m = 7.910 gr.; t_1 = 1100°.		
21.03	23.602	0.1600	21.08	23.684	0.1606
22.42	24.983	0.1597	21.16	23.779	0.1615
m = 11.120 gr..			22.26	24.866	0.1609
22.32	25.643	0.1610			
22.49	25.794	0.1601			
		Mean 0.1602			Mean 0.1610
m = 10.601 gr.; t_1 = 1200°.			m = 10.234 gr.; t_1 = 1250°.		
22.08	25.86	0.1595	21.64	25.476	0.1607
22.01	25.83	0.1610	22.01	25.86	0.1613
23.64	27.41	0.1594	21.32	25.16	0.1610
21.81	25.61	0.1601			
		Mean 0.1600			Mean 0.1610

1.235 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=13.160 gr.; t_1=100°.			m=13.160 gr.; t_1=200°.		
22.892	23.117	0.1170	23.023	23.550	0.1192
22.645	22.872	2.1174	22.896	23.426	0.1198
23.001	23.227	0.1172	22.697	23.227	0.1195
23.023	23.250	0.1176			
		Mean 0.1173			Mean 0.1195
m=11.107 gr.; t_1=300°.			m=9.765 gr.; t_1=400°.		
22.456	23.180	0.1237	21.346	22.238	0.1270
22.678	23.395	0.1226	21.062	21.961	0.1279
22.797	23.520	0.1236	22.347	23.237	0.1270
		Mean 0.1233			Mean 0.1273
m=11.616 gr.; t_1=500°.			m=10.017 gr.; t_1=600°.		
22.459	23.835	0.1306	21.996	23.514	0.1380
22.912	24.295	0.1314	22.103	23.629	0.1388
22.812	24.191	0.1310	22.204	23.722	0.1381
		Mean 0.1310			Mean 0.1383
m=9.182 gr.; t_1=700°.			m=10.405 gr.. t_1=710°.		
23.015	24.745	0.1465	22.378	24.380	0.1473
22.641	24.359	0.1454	22.101	24.095	0.1467
21.625	23.354	0.1461	21.904	23.895	0.1464
		Mean 0.1460			Mean 0.1468
m=7.912 gr.; t_1=730°.			m=8.618 gr.; t_1=750°.		
21.643	23.418	0.1667	21.607	23.597	0.1669
21.406	23.192	0.1677	21.402	23.383	0.1661
m=13.010 gr..			22.091	24.079	0.1668
21.207	24.125	0.1668			
22.014	24.928	0.1668			
		Mean 0.1670			Mean 0.1666
m=8.512 gr.; t_1=770°.			m=10.205 gr.; t_1=800°.		
21.643	23.637	0.1647	21.342	23.813	0.1638
22.014	24.016	0.1655	22.016	24.494	0.1644
21.425	23.420	0.1648	m=8.416 gr..		
			22.204	24.237	0.1635
			21.479	23.519	0.1643
		Mean 0.1650			Mean 0.1640
m=8.416 gr.; t_1=850°.			m=11.716 gr.: t_1=900°.		
20.981	23.102	0.1600	21.070	24.189	0.1596
20.692	22.823	0.1607	20.980	24.106	0.1599
20.771	22.901	0.1605	21.013	24.150	0.1605
		Mean 0.1604			Mean 0.1600
m=10.502 gr.; t_1=1000°.			m=9,324 gr.; t_1=1100°.		
21.467	24.544	0.1577	21.436	24.495	0.1586
21.601	24.687	0.1582	21.603	24.645	0.1593
20.902	23.983	0.1578	20.608	23.630	0.1591
21.441	24.522	0.1579			
		Mean 0.1579			Mean 0.1590

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 9.210 gr.; t_1 = 1200°.			m = 9.810 gr.; t_1 = 1250°.		
20.463	23.723	0.1580	20.202	23.840	0.1588
21.210	24.483	0.1587	20.341	24.000	0.1597
22.104	25.370	0.1585	22.107	25.747	0.1591
		Mean 0.1584			Mean 0.1592

1.41 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 13.121 gr.; t_1 = 100°			m = 13.121 gr.; t_1 = 200°.		
23.001	23.228	0.1180	23.002	23.532	0.1202
23.010	23.236	0.1177	22.976	23.504	0.1197
23.011	23.238	0.1184	23.107	23.635	0.1198
23.101	23.328	0.1183	23.109	23.639	0.1203
		Mean 0.1181			Mean 0.1200
m = 11.091 gr.; t_1 = 300°.			m = 10.205 gr.; t_1 = 400°.		
23.014	23.736	0.1237	23.412	24.344	0.1277
23.212	23.936	0.1242	23.616	24.546	0.1274
22.686	23.411	0.1241	23.504	24.436	0.1276
			22.898	23.829	0.1273
		Mean 0.1240			Mean 0.1275
m = 8.863 gr.; t_1 = 500°.			m = 8.412 gr.; t_1 = 600°.		
22.672	23.729	0.1314	24.001	25.279	0.1388
22.506	23.568	0.1321	23.678	24.959	0.1390
23.010	24.070	0.1319	22.986	24.273	0.1395
		Mean 0.1318			Mean 0.1391
m = 8.561 gr.; t_1 = 700°.			m = 8.561 gr.; t_1 = 710°.		
22.865	24.477	0.1465	23.015	24.659	0.1471
22.624	24.243	0.1469	23.102	24.755	0.1479
		Mean 0.1467			Mean 0.1475
m = 9.216 gr.; t_1 = 730°.			m = 12.312 gr.; t_1 = 750°.		
22.441	24.509	0.1670	22.981	25.805	0.1663
22.861	24.938	0.1678	23.016	25.832	0.1658
23.210	25.276	0.1670	23.108	25.930	0.1662
23.012	25.084	0.1674			
		Mean 0.1673			Mean 0.1661
m = 9.203 gr.; t_1 = 770°.			m = 8.216 gr.; t_1 = 800°.		
22.020	24.179	0.1651	22.719	24.709	0.1640
22.056	24.222	0.1657	22.802	24.801	0.1648
22.812	24.968	0.1651	23.027	25.017	0.1641
		Mean 0.1653			Mean 0.1643
m = 12.224 gr.; t_1 = 850°.			m = 12.224 gr.; t_1 = 900°.		
23.101	26.214	0.1623	22.208	25.468	0.1601
23.205	26.327	0.1628	22.341	25.590	0.1596
23.310	26.424	0.1624	m = 7.509 gr..		
			22.412	24.413	0.1598
			22.017	24.028	0.1605
		Mean 0.1625			Mean 0.1600

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=11.103 gr.; t_1=1000°.			m=8.464 gr.; t_1=1100°.		
21.981	25.193	0.1558	21.204	23.931	0.1572
21.675	24.902	0.1565	20.985	23.723	0.1578
21.212	24.431	0.1560	21.101	23.834	0.1575
		Mean 0.1561			Mean 0.1575
m=8.691 gr.; t_1=1200°.			m=10.208 gr.; t_1=1250°.		
21.214	24.272	0.1571	20.104	23.847	0.1570
20.668	23.745	0.1580	21.421	25.193	0.1584
22.444	25.502	0.1573			
		Mean 0 1575			Mean 0.1577

1.575 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m=14.192 gr.; t_1=100°.			m=14.192 gr.; t_1=200°.		
23.103	23.350	0.1188	23.012	23.586	0.1203
23.013	23.260	0.1194	22.459	23.036	0.1207
23.024	23.270	0.1187	22.618	23.192	0.1200
23.042	23.289	0.1191	22.246	22.826	0.1210
		Mean 0.1190			Mean 0.1205
m=12.101 gr.; t_1=300°.			m=13.002 gr.; t_1=400°.		
20.014	20.816	0.1246	21.313	22.504	0.1274
20.023	20.829	0.1253	21.623	22.819	0.1280
20.613	21.416	0.1251	22.619	23.812	0.1280
		Mean 0.1250			Mean 0.1278
m=10.104 gr.; t_1=500°.			m=9.711 gr.; t_1=600°.		
22.505	23.715	0.1320	20.020	21.514	0.1396
21.509	22.728	0.1327	21.200	22.697	0.1402
21.624	22.835	0.1319	22.401	23.889	0.1396
		Mean 0.1322			Mean 0.1398
m=9.641 gr.; t_1=700°.			m=9.641 gr.; t_1=710°.		
22.536	24.357	0.1468	22.025	23.887	0.1478
22.728	24.556	0.1474	22.501	24.354	0.1472
		Mean 0.1471			Mean 0.1475
m=10.204 gr.; t_1=730°.			m=8.811 gr.; t_1=750°.		
22.429	24.718	0.1670	21.342	23.377	0.1669
21.318	23.622	0.1678	22.004	24.029	0.1662
22.347	24.638	0.1671	22.108	24.139	0.1667
		Mean 0.1673			Mean 0.1666
m=7.912 gr.; t_1=770°.			m=8.616 gr.; t_1=800°.		
20.236	22.107	0.1660	22.598	24.699	0.1651
21.614	23.491	0.1668	21.717	23.829	0.1658
21.489	23.358	0.1661	22.714	24.817	0.1653
		Mean 0.1663			Mean 0.1654

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 10.222 gr.; t_1 = 850°.			m = 6.616 gr.; t_1 = 900°.		
21.020	23.667	0.1645	21.456	23.260	0.1633
20.886	23.522	0.1638	21.226	23.023	0.1626
21.602	24.234	0.1637	m = 11.887 gr..		
			22.312	25.549	0.1635
			20.688	23.893	0.1626
		Mean 0.1640			Mean 0.1630
m = 11.887 gr.; t_1 = 1000°.			m = 13.333 gr.; t_1 = 1100°.		
21.234	24.771	0.1602	20.024	24.288	0.1561
22.104	25.636	0.1601	20.202	24.479	0.1566
22.101	25.624	0.1597	20.305	24.579	0.1565
		Mean 0.1600			Mean 0.1564
m = 13.432 gr.; t_1 = 1200°.			m = 11.412 gr.; t_1 = 1250°.		
20.406	25.089	0.1558	20.022	24.179	0.1560
20.608	25.299	0.1561	20.102	24.285	0.1570
21.719	26.397	0.1558	21.137	25.295	0.1562
		mean 0.1559			Mean 0.1564

2.84 % Carbon Steel.

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
m = 14.144 gr.; t_1 = 100°.			m = 14.144 gr.; t_1 = 200°.		
23.010	23.267	0.1244	23.049	23.651	0.1268
23.021	23.280	0.1255	23.255	23.860	0.1274
23.146	23.403	0.1247	23.277	23.879	0.1268
23.244	23.500	0.1246			
		Mean 0.1248			Mean 0.1270
m = 13.313 gr.; t_1 = 300°.			m = 13.313 gr.; t_1 = 400°.		
22.864	23.775	0.1300	23.025	24.290	0.1328
22.635	23.544	0.1297	23.555	24.813	0.1322
22.505	23.421	0.1306	22.715	23.978	0.1325
		Mean 0.1301			Mean 0.1325
m = 11.313 gr.; t_1 = 500°.			m = 11.123 gr.; t_1 = 600°.		
22.503	23.904	0.1366	22.898	24.644	0.1432
22.608	24.011	0.1372	21.713	23.461	0.1431
21.719	23.129	0.1372	22.724	24.464	0.1427
		Mean 0.1370			Mean 0.1430
m = 10.101 gr.; t_1 = 700°.			m = 10.101 gr.; t_1 = 710°.		
22.102	24.054	0.1501	20.608	22.597	0.1504
23.024	24.981	0.1507	21.505	23.499	0.1510
			22.403	24.391	0.1507
		Mean 0.1504			Mean 0.1507
m = 9.712 gr.; t_1 = 730°.			m = 8.614 gr.; t_1 = 750°.		
21.035	23.208	0.1662	20.435	22.413	0.1657
22.102	24.276	0.1665	21.293	23.278	0.1665
20.698	22.872	0.1662	22.012	23.987	0.1658
		Mean 0.1663			Mean 0.1660

t_0	t_2	M.s.h.	t_0	t_2	M.s.h.
$m=9.138$ gr.; $t_1=770°$.			$m=9.134$ gr.; $t_1=800°$.		
20.495	22.660	0.1665	21.111	23.354	0.1660
21.222	23.374	0.1657	21.232	23.463	0.1651
			20.333	22.574	0.1657
		Mean 0.1661			Mean 0.1656
$m=8.163$ gr.; $t_1=850°$.			$m=7.617$ gr.; $t_1=900°$.		
21.045	23.162	0.1647	20.135	22.232	0.1647
21.078	23.203	0.1653	21.719	23.819	0.1652
21.326	23.450	0.1653	20.426	22.524	0.1648
		Mean 0.1651			Mean 0.1649
$m=10.235$ gr.; $t_1=1000°$.			$m=10.403$ gr.; $t_1=1100°$.		
21.425	24.544	0.1640	20.055	23.432	0.1583
22.317	25.452	0.1650	22.401	25.800	0.1597
21.314	24.437	0.1642	22.005	25.391	0.1590
20.424	23.554	0.1644			
		Mean 0.1644			Mean 0.1590