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Similarity of the Magnetic Change in Cementite and Ferrite

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THE purpose of this paper is to present evidence that the transformation of cementite from the para-magnetic to the non-magnetic state is accompanied by

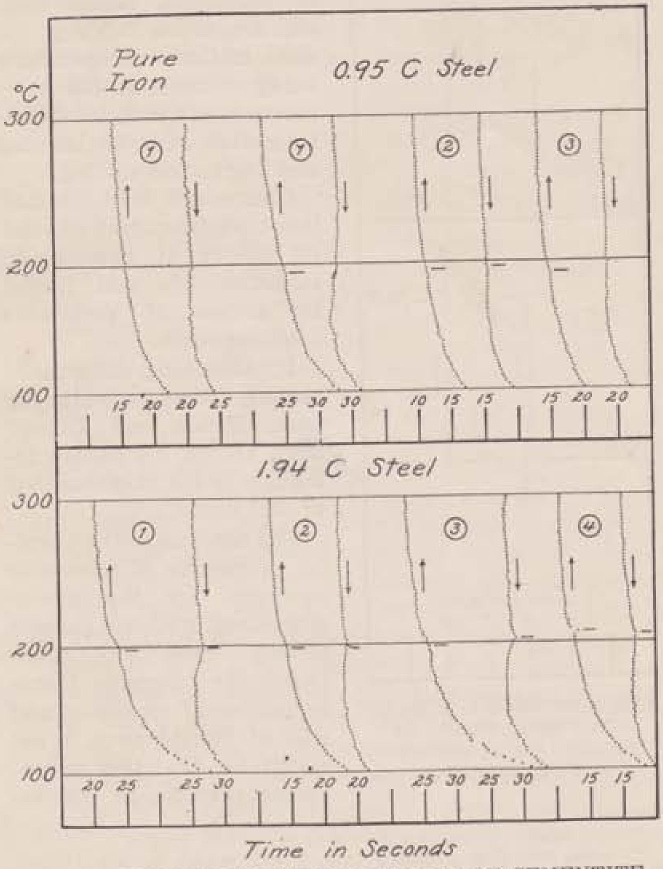

FIG. 1. THERMAL CURVES IN REGION OF CEMENTITE TRANSFORMATION

a detectible thermal effect similar to that accompanying the corresponding transition in pure iron. This behavior of cementite as exhibited in steels and cast iron,

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in which the carbon is in the form of free cementite in its ferrite matrix, was probably discovered by Wologdine[1] and has been studied by means of magnetic methods by Honda[2] and by Smith[3].

Separating the cementite from its matrix of ferrite its transformation has been studied by Honda and Murakami[4] and by Ishiwara[5]. Honda and Murakami, by means of this method, determined the critical temperature of this transformation of cementite, which they call Ao, to be 215 deg. C., the critical temperature being defined as the temperature at which the transformation ends on heating and begins on cooling.

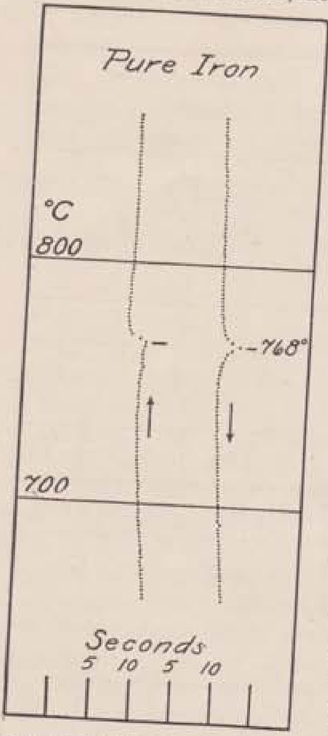

FIG. 2. THERMAL CURVES OF PURE IRON IN REGION OF A_2 TRANSFORMATION

Chevenard[6] has detected this transformation in steel by means of expansivity measurements and Iitaka[7] by means of resistance measurements.

By obtaining differential cooling curves on white pig iron, Honda and Takagi[8] have shown an obtuse inflection in the neighborhood of 200 deg. C.

The changes in the physical properties of cementite measured by the above-mentioned authors show a strong resemblance between the magnetic transformation of cementite and that of ferrite, so it is not surprising that this resemblance persists in the be-

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[1]Wologdine: *Compt. Rend.*, vol. 148, p. 776 (1909).
[2]Honda, *Sci. Rep.*, Tohoku Imp. Univ., vol. 2, p. 203 (1913). Honda & Takagi, *Ibid.*, vol. 4, p. 161 (1915). Honda, *Ibid.*, vol. 6, p. 149 (1917).
[3]Smith: *Proc.* Phys. Soc. of London, vol. 25, p. 77 (1912).
[4]Honda & Murakami, *Sci. Rep.*, Tohoku Imp. Univ., vol. 6, p. 23 (1917).
[5]Ishiwara, *Ibid.*, vol. 6, p. 285 (1918).
[6]Chevenard, *Rev. de Met.*, vol. 16, p. 17 (1919).
[7]Iitaka, *Sci. Rep.*, Tohoku Imp. Univ., vol. 7, p. 167 (1918).
[8]Honda and Takagi, *Sci. Rep.*, Tohoku Imp. Univ., vol. 4, p. 161 (1915).

havior of the material upon heating as detected by thermal analysis and reported here. For the purpose of the comparison, thermal curves were taken by the inverse rate method in the manner recently described[3]. The materials studied were a pure iron, a eutectoid carbon steel and a 1.94 carbon iron-carbon alloy of the composition given in Table I.

The pure iron and iron-carbon alloy were prepared as described in Bureau of Standards Scientific Paper 266, and hence any impurities other than those given in the table are present only in minute quantities; the total impurities are probably less than 0.04 per cent.

The thermal curves, in which the behavior of the material of these three compositions when heated over the temperature range 100 to 300 deg. C. is recorded, are shown in Fig. 1, while Fig. 2 shows those of the pure iron when heated over the A_3 range. The steels

TABLE I. CHEMICAL COMPOSITION OF STEELS

	C	Mn	Si	S	P
Pure iron	0.03	0.003	0.005	0.005	....
Eutectoid steel	0.95	0.22	0.24	0.01	0.02
Pure iron-carbon alloy	1.94	.....	0.01	0.005	....

were in the pearlite state and no graphite was present in the 1.94 C steel. It may be noted from the curves that the intensity of the Ao transformation in the 1.94 carbon steel is small in comparison with A_3 of the pure iron, but that it has the same distinguishing characteristics, that is, a gradual approach to the maximum, a lack of definite hysteresis between the maximum on heating and on cooling, and a difference in form between the Ac and Ar inflections which the curve for pure iron shows very clearly. For the sensitivity of the apparatus employed, the transformation, Ao, is only barely perceptible in the 0.95 carbon steel and cannot be detected in instances where vibrations of the building and other extraneous influences mask the heat effect. The inflection, of course, is not visible in the pure iron curve, which has been plotted mainly to show the furnace characteristics over the temperature range investigated. The intensity of the curve inflection of Ao can be magnified by choice of a more sensitive thermocouple if so desired.

The temperature values of the maximum thermal inflection, as noted on the curves, are given in Table II.

[3]Scott and Freeman, Bureau of Standards Scientific Paper 348. Also *Bulletin* 152, A.I.M.E., p. 1.429.

From this table it appears that the maximum of the transformation occurs at a slightly higher temperature in the higher carbon and steel in which the manganese and silicon are practically nil and that in this case its temperature is in the neighborhood of 200 deg. C. Rate of temperature change has no appreciable effect over the range of rates used on its position, as is also the case with A_2 of pure iron[10].

The difference between the temperature given by Honda (215 deg. C.) and the one given here (200 deg. C.) for Ao does not imply an experimental error in either case, for the values are taken as previously defined from non-coincident points on curves which represent a transformation of the continuous type.

TABLE II. TEMPERATURES OF CRITICAL POINT OF CEMENTITE

Per Cent C	Curve No.	Rate of Heating Deg. C. per Sec.	Aco Deg. C.	Rate of Cooling Deg. C. per Sec.	Aro Deg. C.
0.95	1	0.09	194	0.08	...
0.95	2	0.16	191	0.12	...
0.95	3	0.21	192	0.14	194
1.94	1	0.10	198	0.09	199
1.94	2	0.18	199	0.12	200
1.94	3	0.09	199	0.08	202
...	4	0.19	207	0.14	205

Thermal curves taken on a eutectoid and a 1.94 carbon steel show the magnetic transformation of cementite in both, but more marked in the latter. It has the thermal characteristics peculiar to the A_2 transformation of pure iron and occurs as a maximum in the pure iron-carbon alloy at approximately 200 deg. C.

The thermal change at Ao for the carbon tool steel is so small as to be hardly discernible and consequently cannot be confused with the thermal phenomenon observed on heating hardened steels through the same temperature range.

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[10]Burgess and Crowe, Bureau of Standards Scientific Paper, 213, also A.I.M.E., vol 47, p. 665 (1913).