On the Liquidus Line of Fe-Mn Alloys

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Synopsis

The equilibrium diagram of iron and manganese alloys containing more than 50 per cent of manganese was studied by means of the thermal analysis.

The melting point of pure manganese slowly fell with the addition of a small quantity of iron, and the minimum was found at the point of 91 per cent manganese, the temperature being 1240°C.

The $\gamma-\delta$ transformation point of pure manganese rapidly rose with the iron content, and realized the peritectic reaction, liquid $+\delta$ manganese solid solution $\rightleftarrows \gamma$ manganese rolid rolution. The $\beta-\gamma$ transformation point gradually rose with the iron content, and reached the maximum of 1130°C with 91 per cent of manganese, and then slowly fell with the further increase of iron to the eutectoid point of 1025°C with 71 per cent manganese, where the reaction, γ manganese solid solution $\rightleftarrows \gamma$ iron solid solution $+\beta$ manganese solid solution, occurred.

I. Introduction

The equilibrium diagram of Fe-Mn binary system was already studied by present writer and the result was reported at the World Engineering Congress.(1) After that, the transformation points of pure distilled manganese(2), (3) were studied in detail in our laboratory and the behavior of $\gamma-\delta$ transformation was clarified.

The present writer had some doubts about the liquidus and solidus lines of iron-manganese binary alloy series with respect to the studies of iron-manganese-carbon ternary alloy system. As to the liquidus line of iron-manganese alloys, the studies by Rumelin and Fink,(4) and by Gayler(5) had already been reported. In the strict sense of the word, there were some differences between their results. But, in both cases, the liquidus line continuously lowered from iron to manganese side and became almost horizontal in the region with over 70 per cent of manganese. The solidus line was similar to liquidus line. But the transformation point of $M_3(\gamma \rightleftarrows \delta)$ of pure manganese rose comparatively rapidly as the content of iron in manganese increased, and accordingly, at the point where the solidus line met with it, the peritectic reaction had to take place.

If this expectation is true, there must be a question regarding the shapes of solidus and liquidus lines of the widely-used diagram. Therefore, the present

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* The 624 th report of the Research Institute for Iron, Steel and Other Metals.

(1) T. Ishiwara, The World Engineering Congress, Tokyo (1929).

(2) H. Yoshisaki, Sci. Rept., 26 (1937), 182.

(3) M. Isobe, Sci. Rept., RITU, A-3 (1951), 78.

(4) G. Rumelin and K. Fink, Ferrum, 12 (1915), 41.

(5) M. L. V. Gayler, Jour. of the Iron and Steel Inst., 128 (1933), 293.

writer once more attempted to determine with a special attention the liquidus line of this alloy series containing more than 50 per cent of manganese by the method of the thermal analysis.

II. Materials and experimental method

The materials used in this investigation were electrolytic iron and pure distilled manganese purified by the method commonly used in our laboratory.

The carbolundum tube furnace of Tammann's type was used for melting the alloys to prevent carbon from penetrating through the wall of melting vessel during heating or cooling at high temperatures.

A doubled magnesia tube crucible was used as a melting vessel. The melting and the thermal analysis of alloys were done in purified hydrogen atmosphere to avoid the oxidation of sample as well as the penetration of carbon into specimen during heating.

III. Results and discussion

Fig. 1 shows the typical results obtained by the thermal analyses. The transition points on the respective cooling curves are shown in Table 1. The crosses on the lines in Fig. 2 are the results of the present investigation.

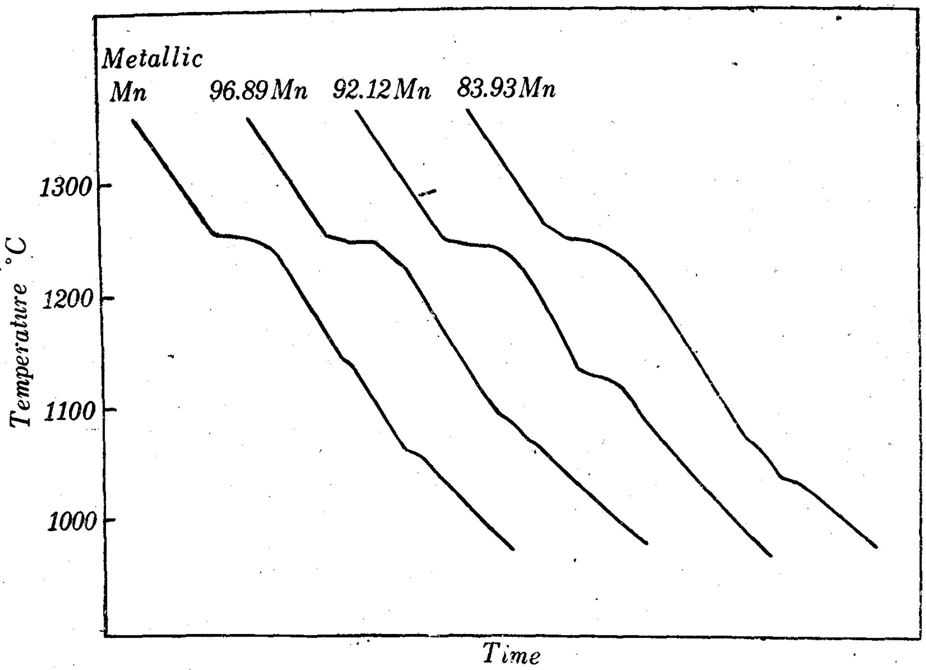

Fig. 1. Cooling curves of iron-manganese alloys.

The melting point of pure manganese is 1252°C. When a small quantity of iron was added to manganese, the melting point gradually fell, and was about 1240°C in the neighbourhood of 91 per cent of manganese, and then rose with iron content. Thus, the results of thermal analyses was in agreement with the writer's expectation, and the minimum point on the liquidus line in the neighbourhood of 91 per cent of manganese was distinctely recognized. The occurrence of this minimum

Table 1.

Specimen No.	Composition %		Melting ranges °C	Transformation temperature in solid state. °C	
	manganese	iron		$\delta_{Mn}-\gamma_{Mn}$	$\gamma_{Mn}-\beta_{Mn}$
1	100.00	0.00	1252	1140	1060
2	98.64	1.36	1251~1247	1210~1150	1090~1065
3	97.17	2.83	1250~1245	1200	1085~1067
4	96.89	3.11	1250~1245	1220	1090~1070
5	94.75	5.25	1247~1244		1110~1085
6	92.12	7.88	1244~1241		1125~1121
7	89.18	10.82	1245~1241		1110~1103
8	83.93	16.07	1260~1250		1075~1036
9	77.13	22.87	1270~1261		1040~1031
10	69.45	30.55	1285~1279		1025($\gamma_{Mn}\rightarrow\gamma_{Fe}+\beta_{Mn}$)
11	63.41	36.59	1309~1286	1160($\gamma_{Fe}-\gamma_{Mn}$)	1025($\gamma_{Mn}\rightarrow\gamma_{Fe}+\beta_{Mn}$)

on liquidus line near the manganese component was not formerly recognized.

The small circles on the line in Fig. 2 are the results of the thermal analyses measured by Gayler. The general tendency of his liquidus line conforms well to the present investigation. But, in his experiments, some alloys with lower melting point were perceptible in the neighbourhood of the minimum point of liquidus, as shown in the Fig. Therefore, it is most likely that he did not measure in detail the trasition temperatures of these alloys and that the liquidus was simply drawn horizontally.

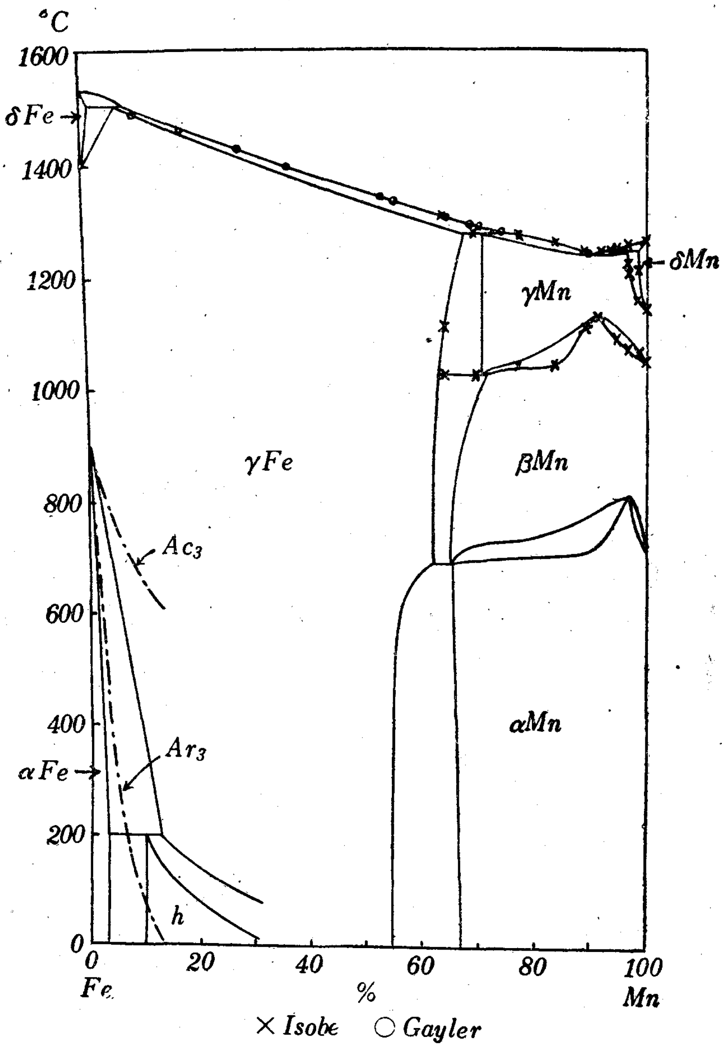

Fig. 2. Equilibrium diagram of iron manganese alloys.

The $\delta-\gamma$ transformation point of pure manganese measured by the present thermal analysis was 1140°C, and rapidly rose with the content of iron, finally meeting with the solidus line, where the peritectic reaction, liquid $+\delta$ manganese solid solution $\rightleftarrows\gamma$ manganese solid solution, occurred. The $\gamma-\beta$ transformation in manganese occurred at 1060°C, which also rose with the iron content in alloys, showing maximum of about 1130°C in the neighbourhood of 91 per cent of manganese. Further increase of iron in manganese gradually lowered the temperature, and with about 71 per cent of manganese, it was about 1025°C, where the eutectoid reaction, γ manganese solid solution $\rightleftarrows$ γ iron solid solution $+\beta$ manganese solid solution, occurred.

Summary

(1) The alloys made from the distilled manganese and the electrolytic iron were carefully studied with thermal analyses and the liquidus line was determined with over 50 per cent of manganese in iron-manganese binary series.

(2) The existence of the minimum on the liquidus line was found at the concentration of 91 per cent of manganese and its temperature was 1240°C.

(3) The $\delta \rightleftarrows \gamma$ transformation point in manganese rapidly rose with the iron content and at the solidus line the peritectic reaction, liquid $+\delta$ manganese solid solution $\rightleftarrows$ γ manganese solid solution occurred.

(4) The $\gamma \rightleftarrows \beta$ transformation in manganese was 1060°C. As iron was added to manganese, the temperature gradually rose and the maximum point of 1130°C appeared with 91 per cent of manganese. After that, the temperature slowly fell and finally met with the two-phase-coexisting region, γ iron solid solution and γ manganese solid solution, at 1025°C with 71 per cent of manganese, where the eutectoid reaction, γ manganese solid solution $\rightleftarrows$ γ iron solid solution $+\beta$ manganese solid solution, occurred.

(5) Combining the present investigation with the previous work, the complete diagram of iron-manganese series was obtained.

In conclusion the present writer wishes to express his hearty thanks to Dr. T. Ishiwara, ex-Director of the Research Institute for Iron, Steel and Other Metals, under whose kind direction the present investigation was carried out and also to Mr. T. Numata for his zealous assistance.