On the Effects of Manganese Oxide and Aluminum Oxide on the Viscosity of High Carbon Ferro-Manganese Slags

Isao TANABE*, Koichi OKU* and Tsugunori HONDA*

1. Introduction

The effects of manganese oxide on the viscosity of high carbon ferro-manganese slag were reported in the previous paper¹⁾. The outline of experiments on the effects of manganese oxide and alumina is presented in this paper.

2. Method of Measurement and Samples

2.1 *Method of measurement* The apparatus used and the method of operation were just the same as in the previous report, and viscosity η was calculated by the equation :

$$\eta = At + B \quad (1)$$

2.2 *Samples* The effects of MnO were investigated by the following way : the mother slag of group A in Table 1 was taken, and the measurement was made in the range of 5~30% of MnO with keeping the content of Al_2O_3 at 6%. The effects of Al_2O_3 were investigated by the following way : the

Table 1 Chemical Composition of Mother Slags Used

Group	No.	MnO	Al_2O_3	CaO	SiO_2	FeO	CaO/ SiO_2
A	1	5.00	6.00	34.71	53.93	0.36	0.64
	2	"	"	39.42	49.21	0.37	0.80
	3	"	"	42.80	45.89	0.31	0.93
	4	"	"	46.56	42.21	0.23	1.10
	5	"	"	50.38	38.25	0.37	1.32
	6	"	"	52.48	36.20	0.32	1.45
B	1	10.00	3.00	33.96	52.68	0.36	0.64
	2	"	"	38.51	48.08	0.41	0.80
	3	"	"	41.84	44.87	0.29	0.93
	4	"	"	45.46	41.21	0.33	1.10
	5	"	"	49.25	37.32	0.43	1.32
	6	"	"	51.27	35.40	0.33	1.45

mother slag of Group B in Table 1 was taken, and the measurement was made in the range of 3~20% of Al_2O_3 with keeping the content of MnO at 10%.

The contents of MnO and Al_2O_3 were adjusted in such a way that the calculated quantities of almost pure MnO and Al_2O_3 were blended with the mother slag in Table 1 to make the required compositions.

3. Results and Discussion

3. *Effects of MnO* The results obtained at 1400, 1350 and 1300°C are summarized in Table 2. The relation between η and MnO content at 1400°C which was classified according to the basicity was shown in Fig. 1. The relation between $\log \eta$ and basicity which was classified according to the MnO content was shown in Fig. 2. From these results, the effects of MnO on η are summarized as follows :

(1) In composition with basicity less than 1.0, η decreases rapidly with increasing content of MnO, and no increase of η is observed in the case of MnO content under 30%. While, in the composition with basicity more than 1.1, η decreases with increasing content of MnO up to 20~25%, but it rather increases with higher content of MnO. These tendencies are more remarkable at higher basicity.

(2) In the range of MnO 5~10%, η has minimum values with basicity of 1.0~1.1, but the range

* Lab. of Azuma Kako & Co., Ltd., Fushiki-Kushioka, Takaoka, Toyama

The original written in Japanese can be seen in J. Electrochem. Soc. Japan **28**, 681 (1960).

Table 2 Effect of MnO Content

Group	CaO/SiO ₂	MnO	η (poise)			$\ln \eta = Q/RT + C$						Inversion points (°C)
						Q (kcal)			$-C \cdot \log_{10} e$			
			1400°C	1350°C	1300°C	High temp.	Low temp. 1	Low temp. 2	High temp.	Low temp. 1	Low temp. 2	
A-1	0.64	5.00	34.52	55.20	—	26.758	—	—	12.265	—	—	—
	"	10.00	17.85	23.51	39.75	10.189	17.915	5.613	4.048	8.155	1.488	1350.6, 1318.4
	"	15.00	11.14	18.29	24.40	8.085	10.590	—	3.056	4.447	—	1280.9
	"	20.00	4.89	6.22	8.63	6.681	9.008	123.774	2.747	3.983	67.709	1352.5, 1281.3
	"	25.00	1.52	2.73	3.44	18.687	7.016	11.930	9.482	3.304	5.996	1357.3, 1302.2
	"	30.00	1.71	1.88	2.80	—	12.580	—	2.340	6.413	—	1358.0
A-2	0.80	5.00	22.46	—	—	89.818	—	—	44.963	—	—	—
	"	10.00	9.29	23.14	—	12.336	26.872	120.097	5.394	12.986	62.559	1350.6, 1318.4
	"	15.00	1.61	7.28	12.23	26.404	10.066	—	13.165	44.333	—	1341.8
	"	20.00	1.52	2.82	3.27	32.231	3.778	10.664	16.444	1.559	5.202	1351.8, 1263.2
	"	25.00	1.50	2.20	3.31	10.490	—	—	5.235	—	—	—
	"	30.00	1.81	2.95	4.94	13.257	39.196	—	6.580	21.324	—	1261.4
A-3	0.93	5.00	14.74	183.64	—	67.232	—	—	33.470	—	—	—
	"	10.00	4.95	10.42	28.04	25.098	30.157	—	12.295	15.122	—	1271.7
	"	15.00	1.97	2.88	5.02	11.013	15.800	—	5.373	8.031	—	1280.9
	"	20.00	1.17	1.90	4.52	6.486	22.427	9.758	3.350	11.658	4.631	1371.1, 1282.9
	"	25.00	1.30	1.47	1.88	6.002	15.443	53.054	3.001	8.174	30.264	1301.7, 1196.4
	"	30.00	1.30	2.12	2.61	19.854	6.754	25.888	10.144	3.283	148.999	1374.7, 1220.2
A-4	1.10	5.00	7.54	14.40	88.84	10.144	46.722	—	4.355	23.684	—	1370.5
	"	10.00	4.08	6.67	19.25	15.627	30.285	16.002	7.469	15.289	7.504	1344.7, 1310.6
	"	15.00	2.89	6.35	15.49	21.857	45.197	—	10.802	23.943	—	1259.8
	"	20.00	1.54	2.36	4.16	10.831	16.600	27.644	5.398	8.454	14.448	1352.3, 1317.2
	"	25.00	2.04	4.51	15.44	28.673	15.638	44.514	14.495	7.383	23.542	1308.7, 1269.2
	"	30.00	3.04	6.57	20.01	21.666	37.670	—	10.689	19.407	—	1311.2
A-5	1.32	5.00	85.63	106.36	194.09	5.579	52.383	—	0.940	26.368	—	1315.5
	"	10.00	47.38	60.22	68.46	5.078	16.869	47.108	0.929	7.430	25.474	1294.0, 1173.3
	"	15.00	30.42	75.55	—	24.931	—	—	11.378	—	—	—
	"	20.00	14.11	—	—	64.219	—	—	31.979	—	—	—
	"	25.00	8.66	23.60	197.91	27.078	55.945	—	13.040	28.366	—	1352.5
	"	30.00	20.41	62.40	—	45.119	5.326	48.298	21.950	1.170	23.882	1379.7, 1359.9
A-6	1.45	5.00	—	—	—	—	—	—	—	—	—	—
	"	10.00	—	—	—	—	—	—	—	—	—	—
	"	15.00	57.51	—	—	—	—	—	—	—	—	—
	"	20.00	40.00	—	—	—	—	—	—	—	—	—
	"	25.00	49.10	—	—	—	—	—	—	—	—	—
	"	30.00	63.10	—	—	—	—	—	—	—	—	—

Notice; — : immeasurable

of minimum values of η extends to lower basicity with increasing content of MnO. Moreover, the ratio of η to basicity increases with the content of MnO.

(3) From the results obtained where the content of Al_2O_3 was kept at 6%, iso-viscous graphs of the slag of $\text{MnO-CaO-SiO}_2\text{-Al}_2\text{O}_3$ system are made and shown in Fig. 3. If the results in Fig. 3 are compared with our equi-conductive graphs of $\text{Fe-Mn slag}^{2)}$, a very close relation is seen between both graphs.

3.2 Effects of Al_2O_3 The results of measurements on the effect of Al_2O_3 at 1400, 1350 and 1300°C are shown in Table 3. The relation between $\log \eta$ and basicity is classified according to the Al_2O_3 contents and the results obtained are given in Fig. 5. From the results shown in Table 3 and Fig. 5, the effect of Al_2O_3 is concluded as the following items.

(1) Under the constant content of Al_2O_3 , η decreases with increasing content of Al_2O_3 ; while, the Al_2O_3 content comes over the certain value, η increases rapidly. The content of Al_2O_3 giving the minimum value of η is nearly 10% in the range of basicity 0.65~1.0; it is changed with the increase of basicity, and is nearly 15% in the range of rather higher basicity, nearly 1.3~1.45.

Fig. 1 Effect of MnO content on η

Fig. 2 Relation among basicity, $\log \eta$ and MnO content

Fig. 3 Iso-viscosity diagram at 1400°C
(Al₂O₃ 6%)

Notice: The diagram is plotted by weight % of three components (CaO, SiO₂, MnO)
Fig. 4 Iso-viscosity diagram at 1400°C
(Al₂O₃ 6%)

(2) As seen in Fig. 5, the effect of increase of Al₂O₃ content on the basicity is remarkably reduced.

(3) From the results obtained, iso-viscous graphs of MnO-CaO-SiO₂-Al₂O₃ system are made when MnO is kept at 10%, and the results are shown in Fig. 6.

3.3 Effects of temperature and activation Energy

(1) The effect of temperature on η is the same as general tendencies of molten salts; that is, η gradually increases with decreasing temperature to a certain value, and then a rapid increase of η is seen with the crystallization of solid phase, which makes the measurement impossible.

(2) The relation between $\log \eta$ and $1/T$ is definitely linear in every experiment. From this result, activation energy Q and constant term C are determined by Eq. (2), and they are shown in Tables 2 and 3.

Table 3 Effect of Al_2O_3 Content

Group	CaO/SiO ₂	Al ₂ O ₃	η (poise)			$\ln \eta = Q/RT + C$						Inversion points (°C)
			1400°C	1350°C	1300°C	Q (kcal)			$-C \cdot \log_{10} e$			
						High temp.	Low temp. 1	Low temp. 2	High temp.	Low temp. 1	Low temp. 2	
B-1	0.64	3.00	18.76	—	—	86.789	—	—	43.474	—	—	—
	"	6.00	17.85	23.51	37.75	10.189	17.915	5.613	4.048	8.155	1.488	1350.6, 1318.4
	"	10.00	8.06	17.77	33.29	15.683	—	—	7.077	—	—	—
	"	15.00	11.13	20.25	35.49	15.709	10.795	17.375	7.061	4.344	8.133	1288.2, 1225.6
	"	20.00	20.80	31.75	49.70	11.510	21.306	—	4.612	10.123	—	1260.8
B-2	0.80	3.00	8.94	25.55	—	14.085	22.784	70.497	6.319	10.860	36.078	1380.4, 1359.9
	"	6.00	9.29	23.14	—	12.336	26.872	120.097	5.394	12.986	62.559	1379.3
	"	10.00	5.52	7.31	11.81	9.019	12.205	—	3.920	5.64	—	1350.3
	"	15.00	8.35	10.53	16.72	7.045	14.470	—	2.718	6.715	—	1330.1
	"	20.00	12.16	19.36	32.73	13.777	5.300	11.781	6.039	1.816	5.207	1287.7, 1197.0
B-3	0.93	3.00	10.18	46.06	—	50.606	192.350	—	25.256	101.569	—	1330.0
	"	6.00	4.95	10.46	28.04	25.098	30.157	—	12.295	15.122	—	1271.7
	"	10.00	4.70	6.04	8.60	4.811	11.103	23.076	1.780	5.149	11.876	1338.9, 1260.3
	"	15.00	7.62	10.16	15.39	7.314	12.747	33.836	2.898	5.778	19.002	1355.4, 1103.3
	"	20.00	8.63	12.56	18.50	10.520	21.317	14.382	5.032	10.366	65.334	1312.3, 1288.8
B-4	1.10	3.00	3.62	7.79	19.92	23.916	13.603	—	11.833	6.105	—	1280.8
	"	6.00	4.08	6.67	19.25	15.627	30.285	16.002	7.469	15.289	7.505	1344.7, 1310.6
	"	10.00	3.42	5.90	8.82	15.783	2.533	49.114	7.610	0.433	26.783	1320.2, 1252.6
	"	15.00	4.69	5.35	9.53	2.678	21.707	4.751	0.716	10.807	1.624	1354.3, 1320.4
	"	20.00	18.73	27.17	51.71	13.915	—	—	5.904	—	—	—
B-5	1.32	3.00	51.44	71.42	117.40	8.855	22.310	—	2.864	10.105	—	1330.8
	"	6.00	47.38	60.22	68.46	5.078	16.869	47.108	0.930	7.430	25.474	1294.0, 1173.3
	"	10.00	10.63	39.93	63.54	50.091	12.949	25.807	24.809	5.713	12.700	1371.2, 1290.9
	"	15.00	9.00	9.79	33.31	3.248	66.447	33.132	0.731	34.906	16.593	1323.0, 1297.1
	"	20.00	17.61	20.74	44.43	2.781	18.663	—	0.193	—	—	1360.0
B-6	1.45	3.00	—	—	—	—	—	—	—	—	—	—
	"	6.00	—	—	—	—	—	—	—	—	—	—
	"	10.00	28.85	59.98	—	20.039	—	—	8.877	—	—	—
	"	15.00	11.75	40.00	—	33.531	—	—	16.227	—	—	—
	"	20.00	30.20	70.96	—	23.385	—	—	10.583	—	—	—

Notice; — : immeasurable

Fig. 5 Relation among basicity, $\log \eta$ and Al_2O_3 content

Fig. 6 Iso-viscosity diagram at 1400 $^{\circ}\text{C}$
(Al_2O_3 6%)

Fig. 7 Examples of relation between $\log \eta$ and $1/T$

$$\ln \eta = Q/RT + C$$

(2)

(3) In almost all samples, a bend point is seen on the linear line of $\log \eta - 1/T$ at higher temperatures than that at which a rapid increase of η due to the solidification is observed. With the exception of few cases, the value of activation energy at the higher temperatures than that corresponding to the bend is 3~20 kcal/g·mol, which is rather small.

The exceptional case of higher values of Q is supposed to be due to the fact that the bend is located at the higher temperatures than 1400°C. Examples of relation between $\log \eta$ and $1/T$ of samples with the higher value of Q are shown in Fig. 7. in comparison with those of ordinary values.

(Received Apr. 14, 1960).

Literature:

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