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PROCESSING OF MANGANESE FURNACE DUST: DRYING AND ZINC OXIDE REDUCTION

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ABSTRACT

Manganese furnace dust collected in smelting of manganese alloys is in the form of a slurry containing oxides of manganese, iron, zinc and other metals, and organics. The water content of the sludge is in the range of 55-60 wt%. Average carbon content, measured by LECO analysis, which includes carbon in the organics and carbonates is 20 wt%. The dust contains (average) 33.4 wt% Mn and 1.3 wt% Zn (dry basis).

Currently, manganese furnace dust is accumulated in large 'settling ponds'. Major factors preventing recycling of the manganese furnace dust to the ferroalloy furnace are handling, due to its high water and organics contents, and the long term accumulation of zinc in the furnaces, which can cause irregularities in their operation. Drying of manganese furnace dust and removing zinc from the dust are important steps to recycle the dust to the smelting furnaces. This paper presents results of drying tests of manganese dust under different conditions and zinc removal from dried dust in sintering experiments. The drying tests were conducted in a muffle furnace at 423 to 973 K in air. On the basis of drying tests, an empirical relationship correlating the moisture content and drying time with temperature and sample thickness was derived.

Zinc oxide was reduced by organics in the furnace dust above 1073 K. The reduction rate increased with increasing temperature with almost complete zinc removal at 1373 K. The effects of sintering time, temperature, moisture content, gas atmosphere, gas flow rate, thickness of a sample, and addition of manganese ore to the dust on zinc removal in sintering experiments have been established.

1 INTRODUCTION

Recycling of metallurgical wastes including dust and sludge formed in cleaning of effluent gas is one of the most urgent issues for metallurgical industries. These dusts contain valuable elements which, when recycled, decrease consumption of raw materials and more importantly, eliminate potentially harmful by-product stockpiles. The Tasmanian Electro Metallurgical Company (TEMCO), Australia, produces ferromanganese and silicomanganese alloys in submerged arc furnaces. Manganese ores are reduced by coke and coal in the furnaces. Electricity supplies the energy for smelting and reduction reactions. Manganese dust, which contains metal oxides, volatiles and organics, is collected from the furnace off-gas in wet scrubbers and then is deposited in settling ponds. The water content of the manganese dust is close to 60 wt%. Therefore, the dust needs to be dried before recycling. The manganese furnace dust contains up to 1.5 wt% of zinc (dry basis) which has to be removed prior to recycling into the smelting furnaces to avoid long term zinc accumulation which can cause irregular charge movement and potential explosions.

Development of industrial technology for the manganese dust recycling requires knowledge of dust drying conditions. The focus of this study is on the drying of manganese furnace dust and the removal of zinc from dried dust during sintering.

2 ZINC IN FERROMANGANESE AND SILICOMANGANESE PRODUCTION

In current operation of TEMCO's sinter plant, the dust collected in the exhaust gas ducts and the electrostatic precipitator is recycled back to sinter raw materials. In the sinter plant, 90.4 wt% of zinc remains in the sinter; the rest is possibly lost with the dust passing through the electrostatic precipitator [1]. Subsequent to this work a wet scrubber has been installed after the electrostatic precipitator to improve dust collection efficiency.

The main sources of zinc for TEMCO's ferromanganese furnaces 1 and 2 are manganese sinter and manganese ore chips. The overall zinc level in the raw materials of these furnaces is 0.019 wt% (coke, coal and slag forming materials were not included). For silicomanganese Furnace 3, which is charged with a significant amount of ferromanganese slag from Furnaces 1 and 2 with very low zinc concentration, the overall zinc level in raw materials is much lower, ie 0.014 wt%. Iron ore is the major source of zinc for this furnace. Raw materials fed into the silicomanganese Furnace 5 contain less ferromanganese slag and more manganese sinter in comparison with Furnace 3. This increases the zinc level in the raw materials to 0.021 wt%. Major sources for zinc are iron ore and export grade manganese sinter.

For all TEMCO's four furnaces, the zinc contents in alloys and slag are low, as most of the zinc leaves the furnace with off-gas and subsequently goes into manganese furnace dust: 76.1 wt% of zinc input into Furnaces 1 and 2 reports to manganese furnace dust via the off-gas. For Furnaces 3 and 5, 58.2 wt% and 78.9 wt% of zinc enters manganese furnace dust, respectively.

Samples of manganese furnace dust, taken from different locations of the manganese furnace dust settling pond, were chemically analysed to determine water content and concentrations of carbon, manganese, zinc and impurities, chemical analysis of organics as well as phase characterisation. Water, carbon, manganese and zinc contents in samples of manganese furnace dust taken from different locations in a settling pond are presented in Table 1. The water content of the furnace dust samples was in the range of 55-60 wt% (wet basis).

Carbon content, measured by LECO analysis, includes carbon of organics and carbonates of different metals. It was in the range 17-22 wt% (dry basis), with average 20 wt%. The average manganese content was 33.4 wt%, and average zinc content is 1.3 wt% (dry basis).

All organics extracts (5.1 wt%) contained C₁₅-C₂₈ aliphatic hydrocarbons, polyaromatic hydrocarbons (PAHs) with 3-6 rings and their derivatives, and sulphur and oxygen containing compounds. The volatile compounds from the extracts covered a wide range of boiling point (503-803 K) and molecular weight (150-400 g). The organics also contained heavier components in the extracts with a similar chemical structure but higher molecular weights and boiling points.

XPS analysis showed that zinc in the furnace dust was present as sulphate and oxide compounds, with a molar ratio of 1:2 between these compounds.

Table 1: Chemical composition of manganese furnace dust (wt%).

Sample location in the settling pond	Depth from surface	Water	Mn	Zn	C
Middle	0~30cm	58.2	32.9	1.43	18.6
Middle	30~60cm	59.1	32.8	1.52	19.5
Middle	60~90cm	58.0	33.4	1.38	21.1
South Middle	0~30cm	58.3	34.7	1.06	17.5
South Middle	30~60cm	55.6	29.9	1.50	21.8
South Middle	60~90cm	55.3	32.9	0.87	19.0
Middle (second batch)		58.2	27.3	0.62	19.2

Note: water content is in wet basis, while carbon, manganese and zinc contents are in dry basis.

3 DRYING OF MANGANESE FURNACE DUST

3.1 Experimental Procedure

The drying tests were conducted in a muffle furnace at 423 to 973 K in air with a flow rate of 2 NL/min. The dust sample (second batch sample in Table 1) was held in a tray of aluminium foil. The shape of a sample was rectangular with 60 mm × 60 mm base and thickness of 10 to 50 mm. The sample temperature was measured by a thermocouple of which tip was placed 2 mm from the sample surface. The change of sample temperature was logged by a personal computer during a drying process.

The dust sample was set into a muffle furnace at the experimental temperature and dried for a certain time. After the experiment, the sample was taken out from the furnace and quenched on a water-cooled iron plate. The initial and final weights of the dust sample were recorded. The change in water content was calculated from the initial water content of manganese dust, which was 58.2 wt%, for different experimental temperatures, sample thicknesses and drying times. A sample temperature remained at 373 K during drying until most of water was removed, although the furnace temperature was in the range from 423 to 973 K. Evaporation of volatiles during this period was negligible. The weight changes of samples fully dried at 423-973 K were within 1.5 wt% relative to the sample's weight change at 383 K, showing that weight loss due to evaporation of volatiles was insignificant. Dry basis water content, or moisture content, was defined as the ratio of the mass of water to the mass of dry material in a sample.

3.2 Experimental Results

In drying tests, change in water content in manganese furnace dust and the surface temperature of the dust sample during drying were measured. Figures 1 and 2 present the results obtained for a rectangular sample with drying surface area of $3.6 \times 10^{-3} \text{ m}^2$ and a thickness of 20 mm. The initial weight of this sample was 102.5 g. The drying process can be divided into three stages. In the first, preheating stage, the mass of water in a sample decreased slowly with time while the sample temperature gradually increased. The duration of this first stage decreased quickly with increasing furnace temperature (Fig. 1). In the second stage, the mass of water in a sample decreased about linearly with time, while the temperature of the sample remained constant. In the current study, the drying tests were conducted under atmospheric pressure, and the observed constant temperature in Fig. 2 was very close to 373 K, the boiling point of water. In the final stage of the drying process, the temperature of the sample quickly increased to the furnace temperature, while the water content decreased with time.

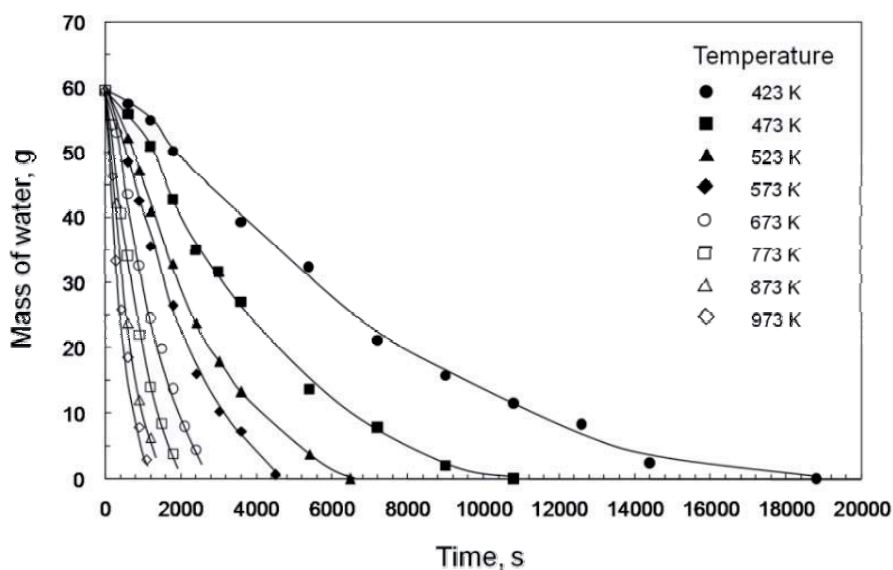


Figure 1: Drying of manganese dust at different temperatures. Sample thickness was 20 mm, surface area $3.6 \times 10^{-3} \text{ m}^2$.

4 ZINC REMOVAL IN THE SINTERING PROCESS

4.1 Experimental Procedure

Sintering of manganese furnace dust (middle 30-60 cm and second batch samples in Table 1) was examined in a vertical tube furnace and in a muffle furnace. Sintering in a muffle furnace was carried out at temperatures between 1373 and 1573 K, using samples from the second batch. Before a sintering test, the dust sample was dried for different durations at different temperatures following the procedure in section 3.1. The thickness of a sample was also changed. The dried dust sample was put on a mullite plate (100 mm × 100 mm × 15 mm) and set in a furnace under air atmosphere. In the vertical tube furnace, a middle 30-60 cm dust sample was dried, pressed to a briquette of 15 mm in diameter and about 10 mm thick, and placed into the alumina crucible; gas flows of air and argon were directed on the top of the crucible through the alumina tube. The zinc content in a sample was analysed by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). About 0.1 gram of ground sample was digested into a solution composed of 6 ml HCl, 2 ml HNO₃ and 2 ml H₂O₂ under microwave, and then diluted to an appropriate concentration for analysis. Carbon content was measured by a LECO carbon and sulphur analyser. The zinc removal was defined as $[(\text{Mass of initial zinc}) - (\text{Mass of final zinc})] / (\text{Mass of initial zinc})$. Manganese furnace dust contains more carbon (19.5 wt% of carbon, dry basis, most in organic components) than is needed for reduction of zinc oxide (1.5 wt%), presuming that the organics did not combust during heating. Thus no additional reductant was used in the zinc oxide reduction experiments. The effects of temperature, gas atmosphere, briquette size, press load, and addition of fine manganese ore to the furnace dust were examined.

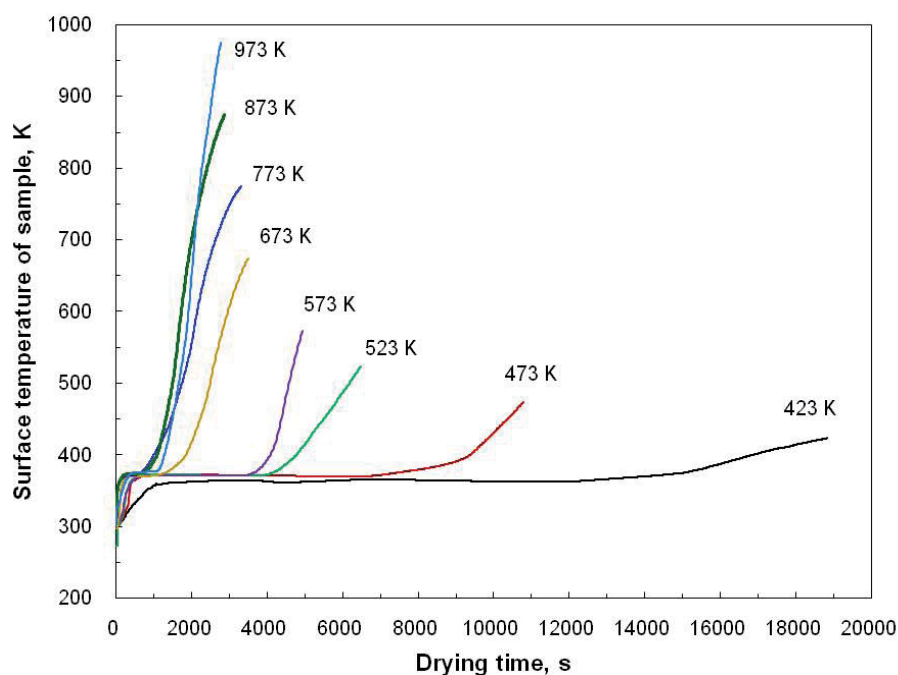


Figure 2: Surface temperature of samples of manganese furnace dust in process of drying at different temperatures.

4.2 Experimental Results

The furnace dust started sintering at approximately 1273 K. The briquette did not gain strength and could be easily broken when the sintering temperature was lower than 1273 K. At 1473 K, the briquette started melting and stuck to the crucible. At 1673 K the molten furnace dust reacted with alumina crucible, causing the bottom to swell and crack. At 1373 K, in both air and argon atmospheres, decomposition and vaporisation of organic components and the decomposition of carbonates resulted in a weight loss of 30-35 wt%. Similar weight losses in both air and argon indicated that combustion of organics inside briquettes was not significant.

4.2.1 Effect of sintering time

It was established in the drying experiments that the organics ignite at 433 K. To avoid loss of organics, samples were dried under such conditions that the organics ignition temperature was not achieved. When the furnace temperature was above 433 K, this was regulated by the drying time. The relationship between sintering time and zinc removal at 1573 K is shown in Figure 3. The initial thickness of the dust samples was 20 mm. Prior to sintering, samples were either fully dried at 423 K or partially dried at the furnace temperature of 873 K for 1200 s. A sample temperature in drying experiments at furnace temperature of 873 K was controlled to be below 433 K, which avoided ignition of the organics in the dust.

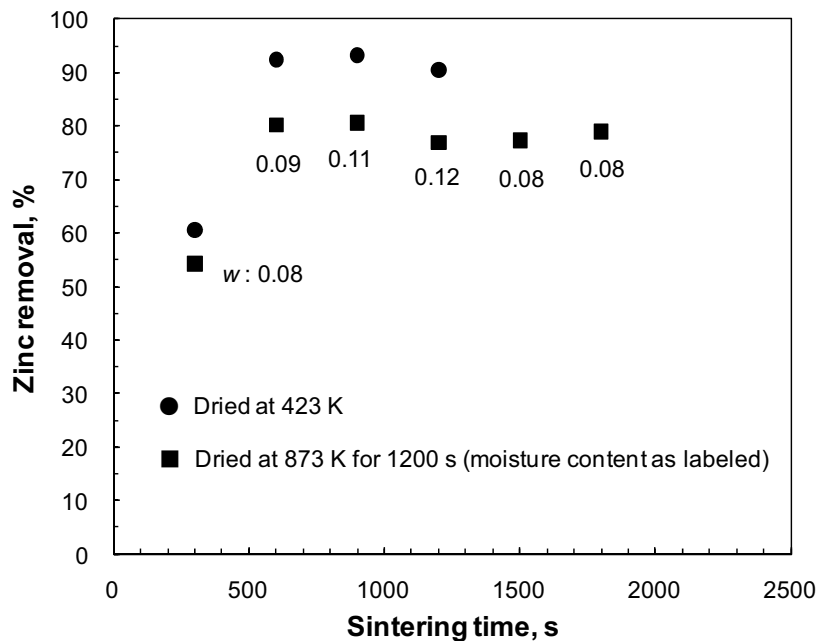


Figure 3: Zinc removal in process of sintering of manganese dust in the muffle furnace at 1573 K. The initial thickness of samples was 20 mm.

After sintering for 300 s, the fully dried samples shrank and were sintered 4 to 5 mm from the surface. Sintering depth increased to 5 to 6 mm after sintering for 600 s, and further to 6 to 7 mm after sintering for 900 to 1200 s. After sintering for 300 s, the zinc removal was 61 %; it achieved more than 90 % after 600 s sintering and did not change with further sintering at this temperature.

Samples dried at 873 K for 1200 s had in average a moisture content of 0.1. They were sintered to 3 to 4 mm from the surface after 300 s, and 5 to 6 mm after 600 to 1200 s sintering. The samples shrank from original thickness of 20 mm to 11 to 12 mm after 1500 to 1800 s. The zinc removal from a sample sintered for 300 s was 51 %; it increased to 80 % after sintering for 600 s, and practically did not change with further sintering. The zinc removal from a fully dried sample was about 10 % higher than that from a sample dried at 873 K for 1200 s.

4.2.2 Effect of temperature

The effect of temperature on zinc removal from the manganese furnace dust in the vertical furnace is shown in Table 2. After 5 minutes sintering at 1323 K there was a decrease in zinc content from 1.5 wt% to 0.072 wt%. Increasing temperature to 1373 K and 1423 K further decreased the zinc content to 0.034 and 0.029 wt%, respectively.

Zinc removal after sintering at different temperatures in the muffle furnace is shown in Figure 4. The initial thickness of the sample in these experiments was 20 mm and the dust was fully dried at 423 K or partially dried at 873 K for 1200 s before sintering. Sintering time for all samples was 1200 s. At 1673 K, the sample melted and reacted with the mullite plate. The depth of sintering of samples at 1373 and 1473 K was about 5 mm from the surface.

Zinc removal increased with temperature between 1073 and 1573 K. The zinc removal for samples dried at 873 K for 1200 s before sintering was about 10 % lower than that for fully dried samples at 423 K, which is consistent with data in Fig. 3.

Table 2: Zinc content of manganese furnace dust sintered in a vertical furnace.

Sample	Temperature, K	Atmosphere	Zn, wt%
Taken from the middle of the pond	Ambient		1.50
Briquette	1323	Air	0.072
Briquette	1373	Air	0.034
Briquette	1423	Air	0.029
Briquette	1373	Ar	0.018
Powder	1373	Air	0.528

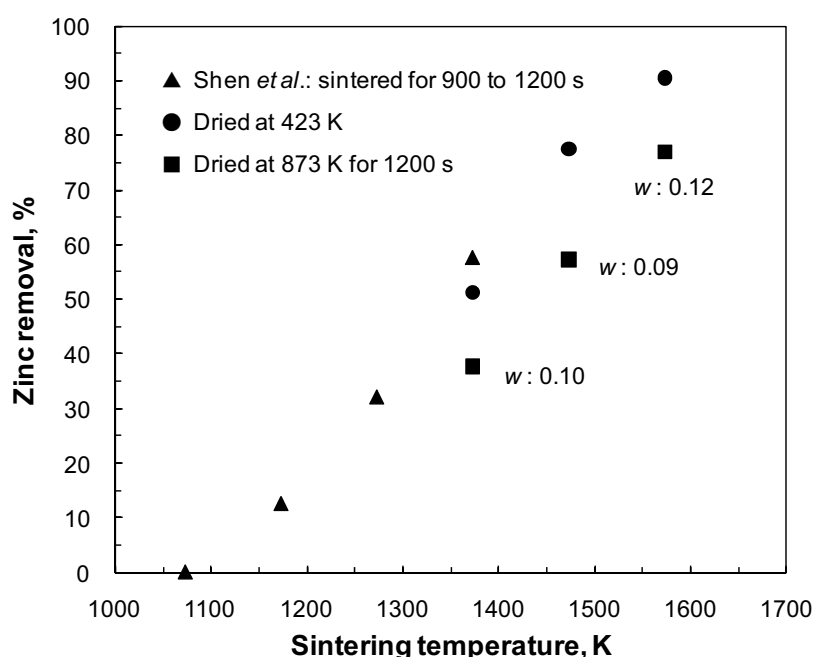


Figure 4: Effect of the sintering temperature on zinc removal. Samples with initial thickness of 20 mm were sintered for 1200 s.

4.2.3 Effect of moisture content in dried manganese furnace dust

The initial thickness of the sample was 20 mm; the dust was dried at either 423 K or 873 K for various durations to attain targeted moisture contents. The samples were sintered at 1573 K for 1200 s. The dust sample shrank but retained a rectangular shape after sintering. The depth of sintering was not visibly affected by the moisture content in the range examined. Increasing moisture content to about 20 wt% had an insignificant effect on zinc removal. When initial moisture content of a sample was 0.21 (0.18 wet basis), zinc removal was 88 %. The zinc removal decreased with further increasing moisture content up to 0.53 (0.35 wet base) and did not change with further increase in moisture. When initial moisture content was 1.00, i.e. 50 wt% water content, 69 wt% of zinc in the manganese dust was removed by sintering at 1573 K for 1200 s.

4.2.4 Effect of thickness of manganese furnace dust sample

The relationship between zinc removal and initial thickness of a sample is shown in **Figure 5**. The dust samples were fully dried at 423 K and then sintered at 1573 K for 1200 s. The sample with 10 mm thickness was almost fully sintered but interior of others was not sintered after 1200 s. A sample with 40 mm thickness cracked and was broken; as a result it was sintered. Other samples also cracked and shrank, but they kept the rectangular shape. The depth of sintering was 6 to 7 mm from

the sample surface. The zinc removal tends to increase with increasing sample thickness.

Several dust samples were dried at 873 K. Drying was stopped before complete removal of the moisture. To maintain similar moisture contents, the drying time was increased with increasing thickness of the sample; it was 1800 s for a 30 mm thick sample, 2400 s for a 40 mm sample, and 3000 s for a 50 mm sample. Then the samples were sintered in a muffle furnace. The sintered layer at surface was 5 to 6 mm thick regardless of the initial thickness of the dust specimens. The zinc removal of these partially dried samples was about 10 % lower than that of corresponding fully dried samples. This difference in the zinc removal, caused by changing drying temperature and degree of drying, was consistent with the data presented in Fig. 3. Similar to fully dried samples, the effect of sample thickness on zinc removal was small.

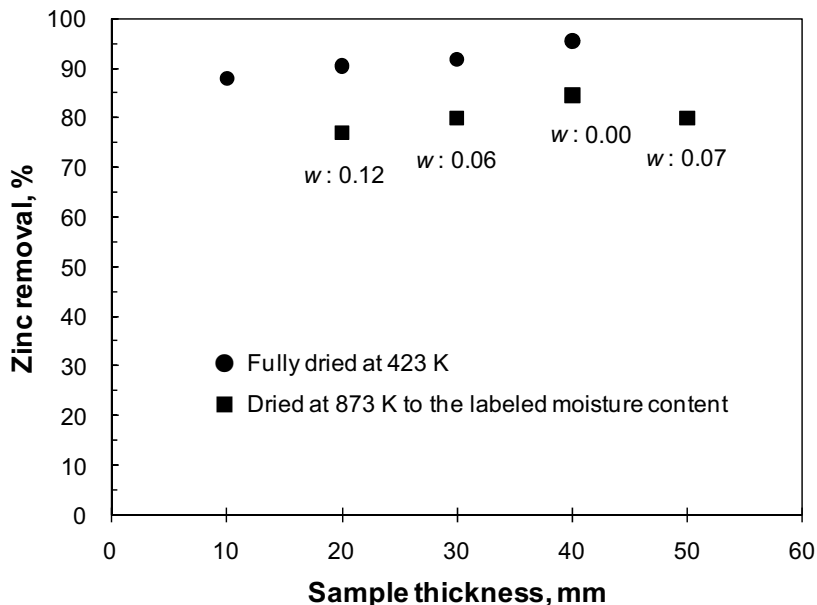


Figure 5: Relationship between zinc removal and the initial thickness of samples. The samples were sintered at 1573 K for 1200 s.

4.2.5 Effect of gas flow rate

The gas flow rate in the vertical furnace changed from 0.5 NL/min to 1.6 NL/min. For experiments in nitrogen, the zinc content in a briquette decreased with increasing flow rate, although it was quite low (0.02 wt%) at a flow rate of 0.5 NL/min. For experiments in air, increasing air flow rate had a detrimental effect on zinc removal, which decreased from 84% to 77% when the air flow rate increased from 0.5 NL/min to 1.6 NL/min.

4.2.6 Effect of addition of fine manganese ore

At TEMCO, fine manganese ore is sintered using a moving strand sinter plant. Utilisation of manganese furnace dust in the sinter plant, if feasible, would include mixing of dust with the ore. The effect of addition of fine manganese ore on the zinc removal rate was examined in the muffle furnace. The briquettes with different manganese furnace dust-to-ore ratios were sintered at 1373 K for 15-20 minutes. The results are shown in **Figure 6**. It can be seen that zinc removal was low when the furnace dust content in briquette was lower than 60 wt%. There was a sharp increase in zinc removal when the furnace dust fraction increased from 60 wt% to 100 wt%. However the removal of zinc was relatively low even for 100 wt% furnace dust briquettes because, in these experiments, briquettes were placed on an alumina plate.

4.2.7 Effect of press load

The effect of the press load in preparing furnace dust briquettes on the zinc removal was examined in the muffle furnace at 1373 K. The press load changed from 5 kN to 25 kN. No effect on the zinc removal was observed. After 20 minutes of sintering, the zinc removal was about 57 % regardless of the load of pressing.

5 DISCUSSION

It is well established [2-4] that drying of wet materials consists of three stages: a short preheating stage, a constant drying rate stage and a final staged with decreasing drying rate.

The constant drying rate stage is not clearly seen in Fig. 1 due to the scattering of experimental data, however its existence follows from experimental data in Fig. 2 which shows a constant surface temperature period in all experimental tests. This stage becomes shorter with increase in drying temperature.

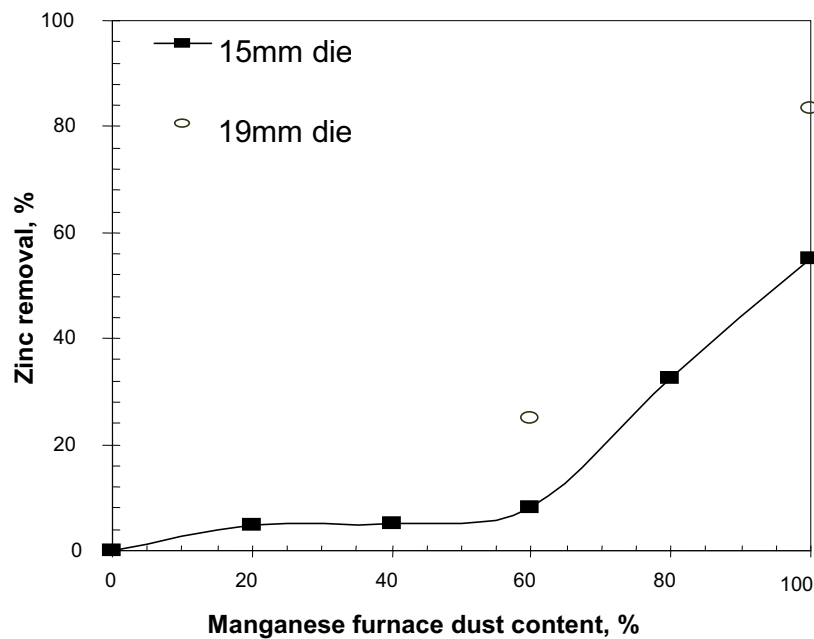


Figure 6: Effect of manganese furnace dust content in the furnace dust-fine manganese ore mixture on zinc removal. The samples were sintered in a muffle furnace at 1373 K for 15-20 minutes.

A plot of moisture content w (which is dimensionless) against dimensionless time τ , (the ratio of drying time to the time needed to fully dry the dust) under different drying temperatures is presented in Figure 7. Ignoring the different stages of drying, the experimental points in the Figure 7 can be approximated by a polynomial formula

$$w = 8.50\tau^5 - 23.4\tau^4 + 22.7\tau^3 - 7.71\tau^2 - 1.53\tau + 1.40 \quad (1)$$

The effect of moisture content on the zinc removal from the samples dried at low temperature of 423 K was small when the moisture content was less than 0.21. When the dust was dried at 873 K for 1200 s, the moisture content was 0.08 to 0.12. However, the zinc removal from samples dried at 873 K for 1200 s was about 10 % lower than from samples dried at 423 K.

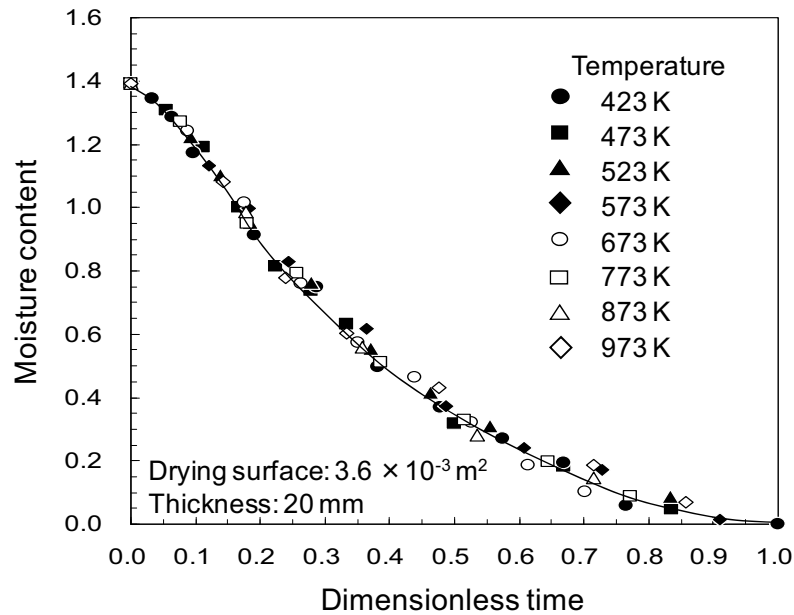
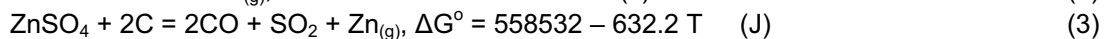
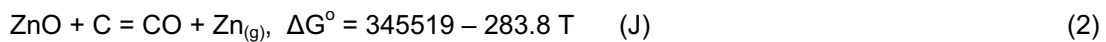


Figure 7: Relationship between the moisture content in the manganese dust and dimensionless time.

Zinc in manganese furnace dust is present in the form of ZnO and ZnSO_4 in the 2:1 ratio. Organics consists of $\text{C}_{15}\text{-C}_{28}$ aliphatic hydrocarbons, polyaromatic hydrocarbons with 3-6 rings and their derivatives, and sulphur and oxygen containing compounds. At the reduction temperatures above 1073 K, organic components are volatile and thermally unstable. Carbon from these evaporated organic components and char formed from thermal decomposition of organics acted as a reductant. To simplify the analysis, the activity of the carbon in the organics was considered to be the same as graphite, i.e. unity. Zinc oxide and sulphate are reduced to zinc vapour $\text{Zn}_{(g)}$ by Reactions (2) and (3).



The zinc vapour diffuses out of briquettes and is removed from the furnace dust. Reactions (2) and (3) are thermodynamically feasible in a wide range of reaction conditions. For example, at 1073 K and CO partial pressure of 10 kPa, equilibrium zinc vapour pressure in reaction (2) reaches 10 kPa. The rate of zinc removal is controlled either by ZnO reduction kinetics or by removal of zinc vapour from briquette by diffusion, or their combination.

Experimental results are sensitive to the gas atmosphere and experimental design. For experiments in nitrogen, the sintering atmosphere is reducing. For experiments in air, particularly when a furnace dust sample was kept on a plate, zinc vapour could be reoxidised to ZnO, which could precipitate on the briquette exterior, although with the excess of organics, conditions in the briquette interior were reducing.

Thus temperature and gas atmosphere are major factors affecting the zinc removal. As shown in Table 2, in a vertical furnace at 1373 K, after sintering in nitrogen a briquette contained 0.018 wt% Zn, while sintering in air under otherwise the same conditions decreased zinc content only to 0.029 wt%. Significantly higher zinc removal rate was observed in nitrogen than in air: 96 % of zinc was removed at 1173 K in nitrogen. To achieve the same removal of zinc in air, the temperature had to be 100 K higher.

Removal of zinc from a furnace dust briquette is different from dry furnace dust powder. As shown in Table 2, sintering of furnace dust powder of the same amount as a briquette at 1373 K in air decreased the zinc content to 0.53 wt%, while sintering of the furnace dust briquette under the same conditions resulted in decrease in zinc content to 0.034 wt%. Obviously, the major difference in these

experiments was sample porosity. Air ingress into the loosely packed furnace dust powder increased the oxygen partial pressure in the sample interior thereby partially reoxidising the zinc vapour.

Reduction of zinc oxide occurred in both air and nitrogen provided that the gas atmosphere in the sample interior was reducing. In experiments in air this was achieved by briquetting the furnace dust. Indeed in experiments with furnace dust briquettes, carbon was not totally consumed. The carbon losses in air and in nitrogen were close and not significantly affected by the sintering temperature.

Removal of zinc requires a reducing atmosphere in the furnace. In air, the zinc vapour was reoxidised and deposited on the crucible walls or on the briquette itself if it was on a plate. In experiments in alumina crucibles, deposited zinc oxide formed whiskers. XRD and EDS spectra of whiskers confirmed that the main composition of the whiskers was zinc oxide. A chemical analysis showed that the whiskers contain up to 77.4 wt% zinc, close to the stoichiometric content of zinc in pure zinc oxide, 80.2 wt%.

The effect of adding fine manganese ore to furnace dust on zinc removal is complex. Figure 6 shows a sharp decrease in zinc removal when the fine ore fraction was increased from 0 to 40 % at 1373 K in the muffle furnace. In experiments in the TGA furnace at 1573 K, zinc removal was only slightly affected by additions of ore up to 60 wt%, however, it decreased sharply when more than 60 wt% of fine manganese ore was added [5]. This can be explained by the difference in the calcination temperature and change in porosity of the briquette made from the furnace dust-ore mixture. The briquette porosity increased with increasing ore content, which had a detrimental effect on the zinc removal, particularly in experiments in air, by allowing oxygen to penetrate into the briquette interior and reoxidise zinc. In experiments at 1573 K, when the briquette was partly molten, the briquette porosity was low, and the effect of the addition of the ore on the porosity was insignificant. When the manganese ore fraction in the briquette exceeded 40-60 wt%, the kinetics of zinc removal slowed down because zinc concentration in the briquette was diluted, and removal of zinc decreased.

At temperatures used in this research, manganese oxides of the ore can be reduced to MnO and iron oxides to metallic iron [5]. However, carbon loss did not increase along with increase in manganese ore content, perhaps due to relatively low reduction rate and short calcination time. Therefore, reduction of manganese ore was not significant under the experimental conditions of this work. "Dilution" of manganese dust by ore addition and relative decrease of organics did not affect the amount of organics available for the reduction of zinc oxide, with which the organics is intimately mixed in the dust.

5 CONCLUSIONS

The drying of the manganese furnace dust was studied at 423 to 873 K. The majority of the water was removed during constant temperature drying period when the sample temperature was close to 373 K. Drying time was directly proportional to the sample thickness and decreased with drying (furnace) temperature. Organics ignite at 433 K; to avoid carbon loss, dust was dried under controlled conditions, so that the sample temperature was below the ignition temperature. The empirical relationship between dimensionless moisture content and drying time was established which allows prediction of the moisture content based on the drying temperature, sample thickness and drying time.

Zinc oxide in manganese furnace dust was reduced to zinc vapour by organics in the furnace dust. Temperature and gas atmosphere are key parameters affecting the zinc removal from the furnace dust. Reduction of zinc oxide from furnace dust briquettes started at 1073 K.

The zinc removal from dried dust samples under controlled conditions increased with increasing sintering temperature. At 1573 K, zinc removal increased with increasing sintering time to 600 s, and practically did not change with further sintering. Sintering of a sample with 20 mm initial thickness was not completed at 1573 K after 1200 s. This did not affect zinc removal. The moisture content of a dried sample up to $w = 0.21$ had little influence on zinc removal. Zinc removal decreased with increasing moisture content up to $w = 0.53$ and did not change at higher moisture contents. Zinc removal from a sample dried at 873 K was about 10 % lower than that from a sample dried at 423 K to the similar moisture content. Manganese furnace dust started to sinter at temperatures above 1273

K. When the temperature was higher than 1473 K, partial melting of manganese furnace dust was observed.

Reduction of zinc oxide was faster in nitrogen than in air under otherwise the same conditions.

Optimal conditions for removal of zinc from the furnace dust include: temperature in the range 1273-1423 K, inert gas atmosphere and furnace dust fraction in the furnace dust-manganese ore mixture above 60 wt%.

6 REFERENCES

- [1] Shen, R., Zhang, G., Dell'Amico, M., Brown, P., Ostrovski, O., Characterisation of Manganese Furnace Dust and Zinc Balance in Production of Manganese Alloys. *ISIJ Int.* 45(2005) 9, pp. 1248-1254.
- [2] Jin, G. (Ed.), "Drying Equipment", Chemical Industry Press, Beijing, China, 2002, 34 (in Chinese).
- [3] Yu, C., Wang, B., Wang X. (Ed), "Handbook of Drying Plant Designs", Chemical Industry Press, Beijing, China, 2005, 22 (in Chinese).
- [4] Nakamura, M., Tatemoto, Y., "Drying technology", Kogyo Chosakai Publishing Inc., Tokyo Japan, (2005), 133 and 194 (in Japanese).
- [5] Shen, R., Zhang, G., Dell'Amico, M., Brown, P., Ostrovski, O., Reduction of Zinc Oxide in Manganese Furnace Dust with Tar. *ISIJ Int.* 46(2006) 1, pp. 1-13.

