LABORATORY STUDY OF SLAG METAL SEPARATION FOR HC FEMN

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ABSTRACT

In the production of manganese ferroalloys, some metal droplets may remain trapped in the tap slag from the furnace, causing a reduction of the saleable production from the smelter. Slag metal separation in trapped slag from an industrial furnace has been investigated by thermodynamic calculations, microscopy analyses and some experimental tests. An industrial slag ladle from HC FeMn production was set aside for solidification of its content. Slag samples in different regions of the ladle have been collected. Slag containing metal pearls was characterized by image processing optical microscopy and EPMA. Metal pearls had a typical diameter of 0.6 mm and their chemical composition was similar to the one of the bulk metal. The amount of oxide solid and liquid phases varies between the investigated area of the ladle, but the composition is the same in all three investigated slags. Slag in the top layer will have lower metal content since solid MnO in the slag settle down and decreases slag viscosity and enhance slag metal separation. The main volume of the ladle has a medium metal content. MnO drained down from the top layer will increase the slag viscosity and give a higher MnO content in the slag phase. Experimental work show that slag-metal separation increases with increasing temperature and decantation time. Additions tested to decrease viscosity or interfacial tension did not have any effect on the slag-metal separation. SiMn, Si and Al additions were tested in order to increase temperature. Al had the most positive effect on slag metal separation.

1 INTRODUCTION

When the slag and alloy is tapped from a single tap hole in a slag process, like HC FeMn, the droplets of one phase may be dispersed into the other. The two phases then have to be separated before casting or transfer to refining. For HC FeMn alloy droplets can be dispersed in the slag and the two phases are then separated by gravity in the metal ladle. With a factor two in difference in spesific gravity this normally does not yield any problem. Situation have, however, been identified were the alloy has not been separated from the slag, and is found as large droplets in the cast slag.

This study was initiated to identify possible methods post taphole to enhance the slag metal separation. As a basis for some of the trials there has been thermodynamical studies performed by Kai Tang (SINTEF) in FactSage thermodynamical software. These calculations will not be shown in this report due to place restrictions.

2 TEST MATERIAL

A slag ladle containing high amounts of alloy was identified and set aside for cooling for approximately 60 hours before emptying. A large piece of the bottom part of the main body was then extracted as the main sample for testing. The reference samples were also extracted from the top layer and the side layer. The chemical composition was determined by XRF. The normalized values, adjusted to a FeO content of 0.5 wt.%, are given in Table 11. It can be seen that there is approximately a percentage point difference in the MnO content of the slag.

As can be seen in Figure 32, there was a large amount of metal droplets in the main body sample. The alloy content of the slag samples were characterized by optical microscopy by Stein Rørvik, SINTEF. It was clearly seen that the industrial sample was quite inhomogeneous in terms of total metal content measured as the percent area of a sample. Two samples were extracted quite close to each other from the main body of the slag ladle. For the two parallel samples the area percent of metal was 9.66% and 3.97%. Further the average droplet size was 0.72 mm and 0.59 mm, respectively. The conclusion of the image analysis is that a more extensive analysis is needed to get a better view of the variation

Table 11: Chemical analysis of the main body slag and the top layer slag from the slag ladle.

Element	**Top layer (wt.%)**	**Main body (wt.%)**
Al_2O_3	13.3	14.9
BaO	1.0	1.0
CaO	21.3	19.6
FeO	0.5	0.5
K_2O	1.1	1.0
MgO	2.6	3.3
MnO	36.4	35.5
S	0.4	0.4
SiO_2	23.2	23.8
Sum	100	100

Figure 32: Picture of the material from the main body of the slag ladle that was the basis for the experiments.

During dismantling of the sample for slag-metal separation experiments a sledgehammer was used. Some of the metal droplets would fall out. This can be seen in Figure 32. "Open" metal droplets may melt before the slag and form a metal layer in the bottom.

The slag samples were investigated by microprobe in order to identify the different phases and their composition. It was of special interest to see if there was any major variation in the slag phase that could be related to amount of metal in the slag. Two samples of each slag were studied. In Figure 33 a microprobe image of a sample of the top layer is shown. The microprobe picture of a sample from the main body is shown in Figure 34. It can be seen that the sample contains smaller and larger metal pearls in a slag phase. The slag phase can also here be divided into the same three phases as the sample of the top layer. The analysis of the slag in the top layer is given in Table 12. The analyses of the metal and slag phases in the sample of the main body are given in Table 14 and Table 13, respectively. No metal was identified in the sample. Three phases were seen in the sample, as indicated in the table: round MnO balls, MnO *dendrites and a mushy zone.*

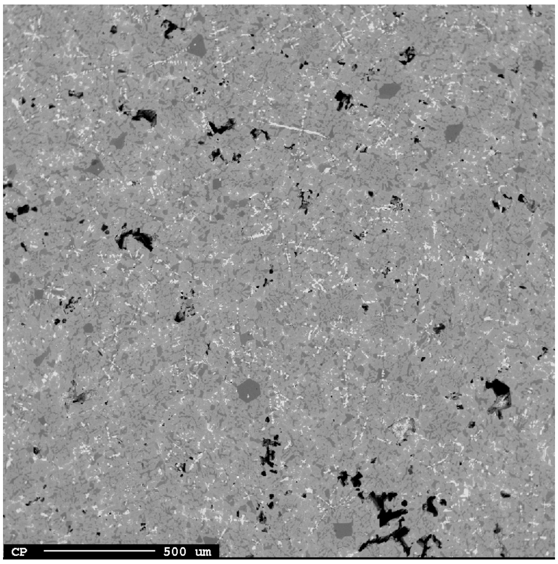

Figure 33: Sample of the top layer of the slag ladle, 40x magnification.

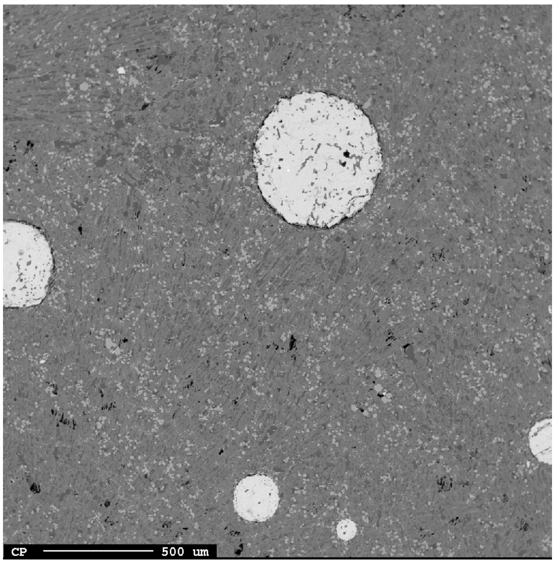

Figure 34: Main body sample, 40x magnification.

Table 12: Slag analyses from the top layer sample of the slag ladle. All values in wt.%

Top layer	**Al_2O_3**	**SO_3**	**MnO**	**SiO_2**	**MgO**	**K_2O**	**FeO**	**CaO**	**TiO_2**	**BaO**	**Tot.**
Round MnO	0.28	0.06	95.53	0.34	2.31	0.07	0.22	0.94	0.17	0.07	100
MnO dendrites	0.35	0.05	94.48	0.37	3.23	0.00	0.24	1.10	0.16	0.02	100
Mushy zone	13.20	1.99	30.86	28.46	2.80	1.28	0.00	20.04	0.56	0.82	100

Table 13: Analysis of the slag phases found in the investigated sample from the main body of the slag ladle. All values in wt.%

	Al_2O_3	**SO_3**	**MnO**	**SiO_2**	**MgO**	**K_2O**	**FeO**	**CaO**	**TiO_2**	**BaO**	**Total**
Rounded MnO	0.32	0.02	93.19	0.38	4.54	0.03	0.2	1.13	0.12	0.05	100
MnO dendrites	0.23	0.02	93.43	0.21	4.58	0.01	0.41	0.92	0.11	0.07	100
Mushy zone	13.19	2.68	29.73	28.23	2.46	1.59	0	20.59	0.6	0.91	100

Table 14: Analyses of the metal pearls found in the sample of the main body of the slag ladle. All values in wt.%

	Al	**Mg**	**P**	**C***	**Mn**	**Si**	**S**	**Fe**	**Ca**	**Ti**	**Tot.**
Small pearls	0.01	0.02	0.000	4.30	80.4	0.03	0.001	15.2	0.05	0.01	100
Big pearls	0.01	0.00	0.000	3.87	81.5	0.00	0.006	14.6	0.00	0.00	100

A comparison of slag ratios, Al_2O_3/SiO_2 (A/S) and $(CaO+MgO)/SiO_2$ (CM/S) have been done in Table 15. Further, the basic and acid oxides and MnO, normalized for $Al_2O_3+SiO_2+CaO+MgO+MnO$, are also shown. Both slags contained a slag phase that was a mixture of rounded MnO pearls and a “mushy” mixture of different phases that has been liquid when the slag was tapped. This is what is normally seen for HC FeMn slags and as expected at temperatures below liquidus, where a solid phase is in equilibrium with the liquid slag phase. While no metal was observed in the top layer, metal pearls up to 2 mm were observed in the main body of the slag ladle.

When comparing the slag chemistry of the top layer with the slag chemistry of the main body, it can be seen that both the solid MnO and the liquid phase had approximately the same composition (Table 15). The difference between the two slags is the variation in the amount of solid MnO particles. The solid phase was MnO with around 5 wt.% MgO in solid solution. The poor slag-metal separation was, in other words, not a result of solid phase different from MnO that caused reduction problems.

Table 15: Calculated values from microprobe analyses. Comparison of slag chemistry.

			Normalized		
	A/S	**CM/S**	**C+M**	**S+A**	**MnO**

Rounded MnO					
Top layer	0.8	9.6	3.2	0.6	95.8
Main body	0.9	15.0	5.7	0.7	93.2
MnO dendrites					
Top layer	1.0	11.8	4.3	0.7	94.7
Main body	1.1	26.4	5.5	0.4	93.5
Mushy zone					
Top layer	0.5	0.8	23.9	43.7	32.4
Main body	0.1	0.8	25.5	35.0	34.5

Elongated (dendritic like) MnO was observed around the metal pearls. This phase had approximately the same composition as the other MnO phase. It is therefore unlikely that the elongated MnO is a result of reaction between metal and slag, and that this is the result of the poor slag-metal separation.

3 EXPERIMENTAL

Experiments were designed based on the gathered material, and the aim was to identify if there are any methods to enhance slag – metal separation, if such a situation is to occur again. A list of the experiments is given in Table 16.

Table 16: List of performed experiments.

Subject	**T** °C	**Holding time** min	**Comment**	**Exp.no.**
Experimental method	1350	30	Induction furnace	E1
	1400	30	Induction furnace	E2
Temperature and Time	1350	30	Resistant heated furnace	E3
	1350	60		E5
	1400	0		E7
	1450	60		E4
	1450	10		E6
Stirring	1350	5/10	Graphite rod (8-stirring)	E8
	1350	10	No stirring (reference experiment)	E9
	1350	5/5/5	Wood sticks	E15
Additives	1350	10	2% SiMn Sprinkling over the melt surface	E10
	1350	10	2% CaF_2 Sprinkling over the melt surface	E11
	1350	10	10% CaF_2 Sprinkling over the melt surface	E12
	1350	10	2% Si Sprinkling over the melt surface	E13
	1350	10	2% Al Sprinkling over the melt surface	E14
	1350	10	Coke-breeze In bottom of charge	E16
	1350	5/10	Sulphur On top+ gas lance (0.5 l/min Ar)	E17

The material from the main body of the slag ladle was the material to be tested further, and will in the following be called *the slag sample*. The size of the slag samples used was maximum 100 mm in diameter due to limits of the crucibles used. Approximately 5 kg of sample was used in each experiment.

The first experiments (E1 and E2) were conducted in a 75 kW induction furnace. A few lumps of the material were charged to a graphite crucible. This heated to 1350°C and 1400°C for E1 and E2, respectively, which were the temperatures measured in the slag ladle during the tap. The heating was followed by a holding time (Table 16). The contents were then cast into a graphite mold for visual evaluation of the slag-metal separation. It can be seen in Figure 35 and Figure 36 that there was a good slag-metal separation for E1 and E2. No metal pearls or droplets were seen in the slag, which was not representative of the observed situation in the slag ladle. It was thus evaluated that further experiments in a resistance heated furnace had to be done to investigate if there is a possible effect of using an induction furnace. Heating to 1350°C was approximately 60 minutes, while 15 minutes longer was raised to 1400°C.

Figure 35: E1 showed a good slag-metal separation

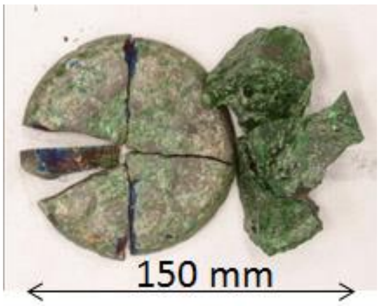

Figure 36: E2 showed a good slag-metal separation.

Experiment E3 was then performed in a resistive heating furnace to 1350°C, with a heating time of 120 minutes. After the experiment the crucible was extracted from the furnace, and set aside for air cooling. The crucible was then cut in two, and the cross section was evaluated. This was the preferred method of evaluation for the further experiments. The result can be seen in Figure 37 that there is a considerable amount of alloy droplets in the slag phase. When taking into account the holding time of 30 minutes, it was judged that this was a good enough replicate of the “status quo” to be able to evaluate an improvement of the slag-metal separation.

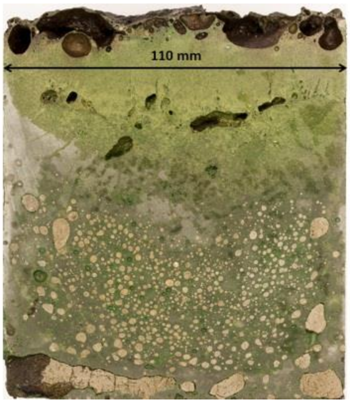

Figure 37: Result of experiment E3. A low degree of slag-metal separation can be seen.

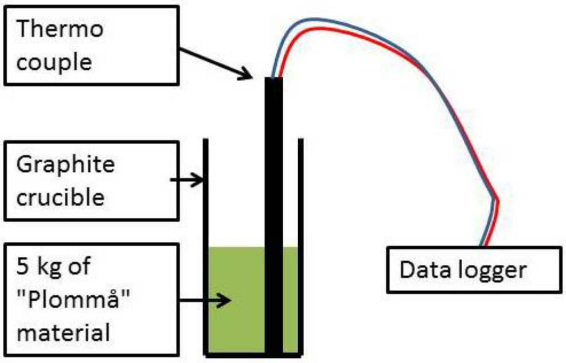

Figure 38: Experimental setup in the resistive heating furnace.

It was thus decided to go further with the experimental setup shown in Figure 38. It should be noted that the inhomogeneity of the sample material makes a quantification of the settling of metal droplets difficult. The loose and exposed metal pearl will also make an evaluation based on the thickness of the metal layer at the bottom difficult. A qualitative visual observation is thus the best available tool for evaluation of the settling. This is judged to be of a low scientific precision, but still gives a good indication. The slag chemistry was also checked, and it was found that the MnO content of the material was approximately 1 wt.% lower after the experiment compared to before the experiment (full sample). This was judged to be within acceptable limits.

3.1 Effect of Temperature and Holding Time

The effect of time and temperature was tested. The results are shown in Figure 39 to Figure 42. It can be seen that the slag-metal separation is increasing with increasing temperature (1350°C to 1450°C. It can also be seen that the slag-metal separation at 1350°C, holding time 30 minutes (Figure 37) is poorer compared to the separation of 1350°C, holding time 60 minutes (Figure 42). For the two experiments performed with a different holding time at 1450°C, no difference in slag-metal separation can be seen. Based on these experiments it was concluded that by keeping the temperature at 1450°C, the slag-metal separation would be promoted. Further, 1350°C was chosen as the temperature for further evaluation of slag-metal separation. This is due to the poor separation seen. If the experiments are able to increase the separation at this temperature, they are expected to have the same effect also at higher temperatures.

Figure 39: E4 shows a good slag alloy separation. T = 1450 °C, t = 60 min.

Figure 40: E7 shows a poor separation with metal droplets still visible. T = 1400 °C, t = 0 min.

Figure 41: E6 shows a good separation. No metal droplets visible. T = 1450 °C, 10 min.

Figure 42: E5 shows a poor slag-metal separation with metal droplets visible. T = 1350°C, 60 min.

3.2 Effect of Stirring

One of the objectives was to study the effect of additives. However, to be able to properly evaluate the effect of additives, mixing these additives into the slag-metal suspension had to be evaluated. Stirring was therefore evaluated. This is experiments E8 and E9 in Table 16.

Stirring was tested by heating the sample to 1350°C. A graphite rod was then used for stirring (10 minutes). The stirring was rather calm of nature and in a “figure 8” motion. The melt was then further held at 1350°C for 5 minutes before extracting the graphite crucible. As a reference, experiment E3 (1350°C) was repeated with a holding time of 10 minutes. The results of the two experiments can be seen in Figure 43 and Figure 44. The results show that stirring the melt in a “figure 8” manner seems to give an increased slag-metal separation compared to only holding the melt. This is probably due to an increased chance of metal droplets meeting and coalescing, which will promote settling.

Stirring was further investigated by introducing a wooden stick to the melt. A wooden stick, approximately 10 mm in diameter was introduced to the melt and held there for 5 minutes. The melt was then held for 5 minutes before extracting the crucible for cooling. When the wooden stick was introduced to the melt, gas evolution was observed. The gas bubbles created is assumed to cause stirring the melt. It can be seen in Figure 45 that there seems to have been an improvement compared to E9 (Figure 43). However, the effect seems to be somewhat limited. It was concluded from the experiments that there should not be stirring in the experiments with additions due to the increased separation seen in the experiments above. A further study of the effect of stirring was also recommended.

Figure 43: E9 show a poor slag metal separation. T = 1350°C, Hold =10 min.

Figure 44: E8 show a good slag-metal separation. T = 1350°C, Stirring 5 min. Hold = 10 min.

Figure 45: E15 shows a positive trend with fewer metal droplets compared to E9.

Figure 46: The cross sections of the crucibles with and without stirring.

3.3 Effect of additives

It was decided to test addition of different additives which was expected to have positive effect on the metal-slag separation due to either increase in the temperature due to exothermic reactions (E10, E13, E14) or decrease in viscosity of the melt (E11, E12, E16, E17). The experiments were carried out by adding approximately 2 wt.% of the additive (<3mm) to approximately 5 kg of the sample that had been heated to 1350°C (liquid). 2 wt.% was used, as this is an amount that is realistic to be able to handle industrially. Further, the sample with the additive was held at 1350°C for 10 minutes before extracting the crucible.

Additions of SiMn (E10), Si (E13) and Al (E14) were planned, where the two latter additions were to check experimentally if the reactions would occur. It is expected that Si and Al metal will react with MnO in the slag according to the reactions below. Addition of coke fines to react according to equation (3) gives is an endothermic reaction. The heat of reaction for the chemical reactions (from HSC thermodynamical software [2]) is given.

$$2(MnO) + [Si] = (SiO_2) + 2[Mn] \qquad \Delta H_{1873K} = -202.8 \text{ kJ} \qquad (1)$$

$$2[Al] + 3(MnO) = 3[Mn] + (Al_2O_3) \qquad \Delta H_{1873K} = -464.8 \text{ kJ} \qquad (2)$$

$$(MnO) + C(s) = [Mn] + CO(g) \qquad \Delta H_{1873K} = 249.7 \text{ kJ} \qquad (3)$$

where: () are oxides in slag
[] are metals

The expected effect of addition of SiMn (68%Mn, 18%Si and 14%Fe, 25°C) in experiment E10 and Si (high purity poly Si) was an *increase* in the bath temperature caused by the silicothermic reaction according to equation (1). Thermodynamic calculations using HSC thermodynamical software, estimated that the addition of SiMn and Si would yield an increase of approximately 30°C and 270°C, respectively. This would lower the viscosity of the melt and thus promote slag-metal separation. By lowering the MnO content, the viscosity would decrease further.

As shown in Figure 47, the addition of SiMn fines resulted in a temperature drop of about 80°C at the top of the crucible, caused by the temperature of the SiMn. This temperature drop was within the expected order of magnitude due to the addition of cold SiMn fines (25°C) onto the hot slag/metal-bath surface. The increase in temperature was measured to about 3-4°C, 10 minutes after the addition, and not 20°C as expected from the thermodynamic calculation. As shown in Figure 48, the metal is still not fully separated from the slag.

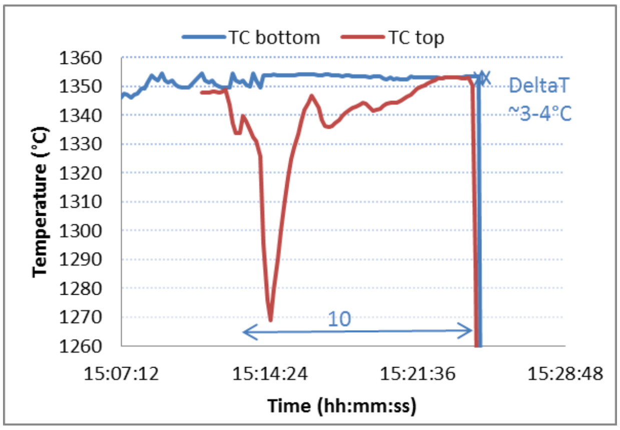

Figure 47: Temperature measured at the bottom of the crucible and at the upper 3 cm of the bath of experiment E10.

Figure 48: Experiment E10 showing good slag-metal separation on the right side and poor separation of the left side.

The Si-fines did not dissolve completely during 10 minutes holding time. Approximately 60 % of the Si-fines were estimated to be dissolved. An increase in the temperature can be seen after addition of Si (Figure 49), however, metal droplets can still be observed in the slag (Figure 50)

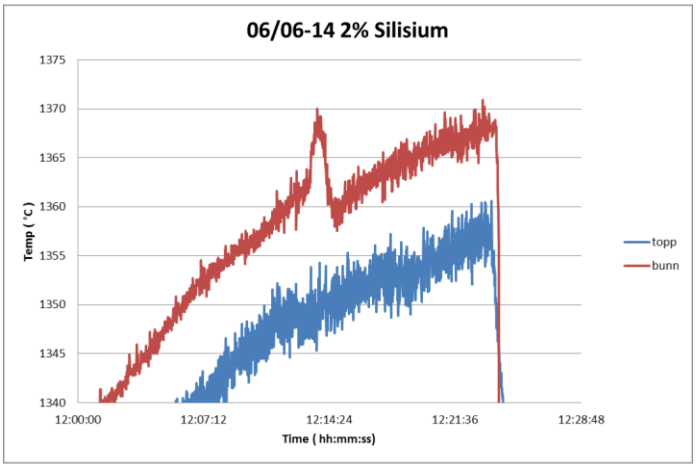

Figure 49: Temperature development during experiment E13, where 2 wt.% Si was added. An increase in temperature can be seen.

Figure 50: Metal droplets can still be seen in the slag after the Si has reacted in experiment E13.

The expected effect of addition of Al was an *increase* in the bath temperature caused by the aluminothermic reaction shown in equation (2). Al fines, needles; 1-3 mm of Al cast alloy (~5% Mg/5% Si) were added in the bath during 5 minutes with no stirring. As with the Si in experiment E13, not all the added Al dissolved in the slag. Some of the aluminum was left at the top. The temperature development show an increase in temperature when the Al is added (Figure 51) to about 1400°C. The expected increase calculated by use of HSC Thermodynamical software was about 190°C. The cross section of 2 % Al fines is shown in Figure 52 where the Al that has not been melted can be seen on the top. Despite this, it seems that Al addition has positive effect on the slag-metal separation.

According to thermodynamic calculations CaF_2 will reduce the liquidus temperature of the slag substantially. However, the temperature is simultaneously expected to decrease, which will also influence the viscosity. CaF_2 were dissolved in the bath during 2 minutes for 2 wt.% addition (E11), while for 10 wt.% addition (E12) there were not melted material at the top after the experiment (Figure 54). For E11 (Figure 53) it can be seen that the higher levels of the slag contains very little or no metal droplets, but there is a significant amount of metal droplets in the lower part of the crucible. In experiment E12 it can be seen that there is very poor slag-metal separation (Figure 54). It can thus be concluded that addition of CaF_2 does not significantly improve the slag-metal separation.

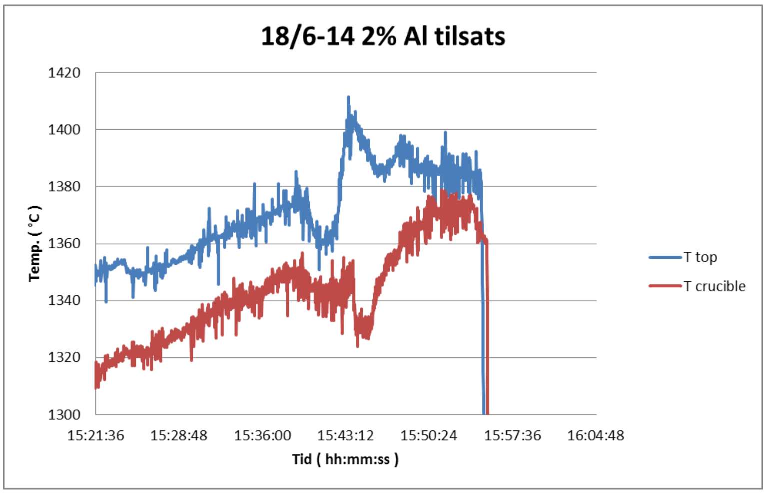

Figure 51: The temperature during the experiment with addition of 2 % Al. An increase in temperature can be seen at the top of the crucible.

Figure 52: The experiments show a good slag alloy separation for E14 when Al is added.

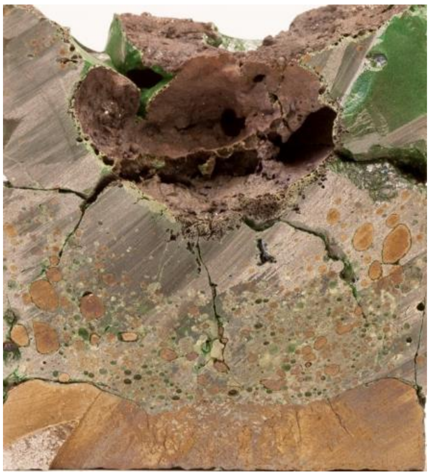

Figure 53: Cross section of experiment E11 after addition of 2 wt.% CaF_2.

Figure 54: Cross section of experiment E12 after addition of 10 wt. % of CaF_2.

Coke breeze (1-3 mm) was added to the cold charge in the bottom of the crucible. The expected effect was that coke particles would cause gas evolving (CO) according to Equation (3), thereby contribute to stirring and improved separation. The cross section of the crucible Figure 55 does not show any significant effect. The expected effect of addition of Sulphur (E17) was to reduce the interfacial tension between slag and metal, and thereby contribute to improved separation. It is known from iron industry that the interfacial tension between slag and iron is strongly influenced by sulphur [1]. Sulphur powder was added to the melt by sprinkling over the surface of the bath. In this case it was decided to apply some "light" stirring, due to the difference in density of the sulphur and the melt. A lance was placed in the bottom of the crucible with a flow (0,5 l/min) of Argon (demonstrated by have less effect on stirring compared to Figure 8 stirring in unpublished work by H. Olsen, Eramet Norway AS). The addition of Sulphur caused a vigorous combustion on top of the melt. The cross section of the crucible from the experiment is shown in Figure 56, and as we can see from the figure, it is not possible to observe any significant effect.

Figure 55: The addition of coke breeze in experiment E16 demonstrates that this does not improve slag-metal separation.

Figure 56: Adding sulphur to the sample does not improve the slag-metal separation. (E17)

4 DISCUSSION

The main objective of this work was to investigate:

- Possible causes related to properties of the tapped slag, for alloy being trapped in slag
- Possible methods to reduce the metal losses by treatment of the tap slag

Slag from one tapping was investigated. This was from a tapping with high amount of metal trapped in the slag. The results of this investigation have not been compared with a standard slag in order to compare differences between slag with low metal losses and slag with high metal losses. It has thus not been possible to find out whether the high metal losses are a result of changes in slag compositions. The investigation has therefore been concentrated towards finding methods to better separate metal from slag in the already tapped slag. Metal in the slag ladle, the material studied here, was entrapped in the slag when it floated over to the slag ladle and was later not able to be separated from the slag. The slag was cooled in the ladle for 60 hours. Back reactions between metal and slag can therefore not be excluded.

The main body has the highest metal content and highest MnO content in slag (39.2%) of the two investigated samples. Top slag layer has lowest metal content and medium % MnO content in the slag (36.4 %). In the main body of the ladle, the metal droplets had an average size around 0.65 mm. Size of metal droplets was not investigated in the two other samples, but the microprobe pictures indicate that there is no difference in size. The top layer of the ladle contained so few metal pearls that they were not found in the microprobe investigation. Only three samples are too little to draw any conclusions, but the observed differences indicate some mechanisms.

Due to the difference in density between HCFeMn slag (3.75 -4.0 g/cm^3) and HCFeMn alloy (about 7 g/cm^3) the metal is expected to sink down in the ladle, in a rate and to an extent increasing with increasing size of the metal droplets and decreasing with increasing viscosity of the slag. The similar size of the metal droplets in the different samples shows that the difference in amount of entrapped metal in the samples is not a result of differences in size of the metal droplets.

There was no difference between the samples in their composition of metal droplets, MnO balls or "liquid" slag phase. The difference in MnO content of the slags is therefore a result of different amounts of solid MnO balls in the slag phase. Effective viscosity of the slag will increase with increasing amount of MnO balls. Samples with high MnO content are therefore expected to have higher amount of entrapped metal. This is what is observed in the two samples investigated. The higher MnO content in the main body compared to the top layer can result from either of the options:

1. Variations in slag composition from the furnace
2. Segregation in the ladle
3. Back reaction from metal to slag
4. Oxidation from Mn to MnO

Point 3 and 4 is unlikely since increased amount of MnO will give a lower amount of metal due to back reaction of Mn (alloy) to MnO (slag), opposite of what is observed in the microprobe studies. In addition the MnO ball contains around 5 % MgO that must come from the slag and not from the alloy. Both point 1 and 2 are possible, but point 2 is regarded as the most likely. A possible mechanism is then: Segregation in the ladle

At temperatures below liquidus temperature for the slag under equilibrium conditions, the slag will consist of a mixture of solid (rounded) MnO and a liquid slag phase. The amount of solid rounded MnO is, under equilibrium conditions, a function of the total MnO content in the slag and the temperature. During cooling, there is a point where liquid and solid phase does not obtain equilibrium with each other, and in the cold samples there will be a mixture of MnO that was solid at this temperature and a mixture of phases that was liquid at this temperature. This has been observed and described in several cases. To the authors’ knowledge, solidification reactions under different conditions have not been studied. In the top layer MnO that has a higher density than the liquid slag will settle down together with the alloy. This will decrease the viscosity and promote the drainage of the metal. The top layer will therefore have a lower MnO content and a lower metal content than average. In the main body the MnO will settle towards bottom together with some alloy, but the average amount of both MnO and alloy will increase since it receives them from the top layer. The increased amount of rounded MnO increases effective slag viscosity and settling of metal is hindered so it will not drain to the metal layer in the bottom of the ladle. The main body is, in addition a large volume that is insulated by possible sculling in the ladle and the top layer. It will therefore cool slowly. This gives time for formation of rounded MnO instead of dendrites during cooling. A slag with an initial lower viscosity, lower MnO content and higher temperature would have made the settling and the slag-metal separation easier.

The tests clearly show that the metal separated much more easily from the slag when the sample was heated by induction compared to resistive heated furnace. The mechanism was not investigated further, but is believed to be on of the following: 1) induced current in the alloy causes the alloy to heat and melt prior to the slag, and thus enhancing the slag-metal separation. The surrounding slag is heated by thermal conduction from the metal, its viscosity decreases so much that the metal particle is able to drain down, or 2) stirring of the melt that causes metal droplets to meet and coalesce, thus increasing the slag-metal separation. As shown in experiment E8, stirring seems to improve slag-metal separation, thus supporting that induction may cause stirring that increases separation. This was also seen when a wooden stick was introduced to the melt. As a result of the good slag-metal separations when heating the sample by induction, the further experiments were done in a resistance heated furnace.

The effect of both temperature and holding time was investigated. As expected, the experiments showed much better slag-metal separation at 1450°C compared to 1350°C. This is expected due to a decrease in the viscosity with increasing temperature. The separation also increased with increasing holding time. After 60 minutes at 1350°C most of the metal had separated from the slag. However, temperature seems to be more important compared to holding time. At 1450°C nearly full separation was achieved after 10 minutes holding time while there was little separation after 30 minutes at 1350°C. The heating of the crucible will take some time and higher temperature thus gives longer holding time. This was investigated by comparing heating to 1400°C and 0 minutes holding time with 30 minutes holding time at 1350 °C that both takes the same time. A much better separation was achieved by only heating to 1400°C which confirms that temperature is more important compared to holding time.

The addition of 2 wt% SiMn did not induce the expected increase in the temperature. This may be caused by the fact that the SiMn particles were too fine (1-3 mm), and thereby already oxidized and not "prepared" for reaction with MnO. The lack of temperature increase can also be explained by a slight change in the experimental procedure in this particular experiment. The temperature loss through the surface is probably slightly higher compared to the reference experiment, due to introducing one more thermocouple, and the subsequent poorer insulation on the surface of the bath. The experimental setup was improved due to the insulation issue and experiments continued with addition of CaF_2, Si and Al.

Si fines and Al chips were tested to see whether the methodology of exothermic reaction would work at all. The most significant increase in temperature was achieved by addition of Al. Si also showed an increase in temperature, but not as significant as Al. Both of the additions did not show an increase that was within the same order of magnitude of the calculated temperature increase. This may be due to poor mixing and thus some unreacted metal. Temperature loss may be another issue, but since the experiment was performed in a resistive heating furnace, the heat loss is most likely minimized.

No visible effect was observed by addition of CaF_2 (both 2 wt% and 10 wt%) and coke breeze. They were added to lower the viscosity or interfacial tension to increase slag-metal separation. The reason for these results is probably the decrease in temperature when adding room temperature material to the melt. This would cause problems in melting and mixing the materials, as observed for some of the experiments.

Quantification of the slag-metal separations is one of the weaknesses of the method used. Automated image analysis was tried, but did not give good results. However, when comparing the qualitative analyses that are the basis of this paper with a surface analyses made by a student at a later stage [3], the different methods gave the same results.

5 CONCLUSION

The investigated samples from a slag ladle consist of metal pearls around 0.6 mm in diameter entrapped in a slag phase with solid MnO and a liquid slag. The amount of solid and liquid phases varies between the two layers of slag, but their composition is the same in both the investigated slags. Slag in the top layer will have a lower metal content since solid MnO in the slag settle down and decreases slag viscosity and enhance metal separation. The main volume of the ladle has a medium metal content. MnO drained down from the top layer will increase slag viscosity and give a higher MnO content in the slag phase.

Experiments show that increasing temperature and decantation time will increase slag-metal separation. The experiments show that temperature has a higher impact on the separation compared to decantation time. Further, the experiments showed that inductive heating and stirring of the melt improved the slag-metal separation significantly.

The experiments showed that addition of 2 wt.% Al or Si would increase the temperature of the slag by up to 25°C, while an order of magnitude is lower compared to the theoretical increase in temperature. Addition of SiMn fines did not give an increase in temperature. Addition of CaF_2, sulfur and coke breeze to enhance slag-metal separation due to a decrease of the viscosity or interfacial tension was not successful.

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