THE USE OF LD-SLAG AS A FLUXING AGENT IN THE HISARNA PROCESS

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Introduction

HIsarna is a new ironmaking process which is being developed at Tata Steel in IJmuiden in collaboration with European industrial partners ArcelorMittal, Thyssenkrupp Steel Europe, voestalpine Stahl and Paul Wurth. It is a smelting reduction process where granular iron ore and granular coal are directly injected into the process, without the need to agglomerate the ores or to coke the coal. This process intensification alone results in a specific CO_2 emission reduction of 20% per tonne of steel.[1,2]

Further CO_2 emission reductions without carbon capture technology are possible with this process by charging scrap as part of the metallic charge and replacing part of the coal with sustainable biomass. It was demonstrated that a CO_2 emission reduction of more than 50% could be achieved this way.[3] As part of the same European Horizon 2020 project, successful trials were done to replace most of the burnt lime with limestone and dolomite that can be pre-mixed with the iron ore. These successful trials formed the basis for the decision to complete a trial where the limestone and dolomite is replaced with recycled LD-slag.

Using LD-slag in HIsarna

In the HIsarna process, of which a schematic is shown in Figure 1, iron ore is injected in the smelt cyclone at the top of the process. The iron ore melts and partly pre-reduces at this point, after which it drips into the Smelting Reduction Vessel (SRV). Here, coal is injected onto the slag layer where the final reduction takes place, forming liquid hot metal and slag. The slag composition is controlled by injecting burnt lime directly into this slag together with the coal. If part of the burnt lime can be replaced with another source of CaO, the production costs of hot metal can be reduced. Depending on the CaO source, the CO_2 footprint of the process is also

further reduced. To reduce the amount of burnt lime, CaO containing material can be injected in the smelt cyclone together with the iron ore. This could also improve the melting and fluxing behaviour of the ore mixture in the smelt cyclone.

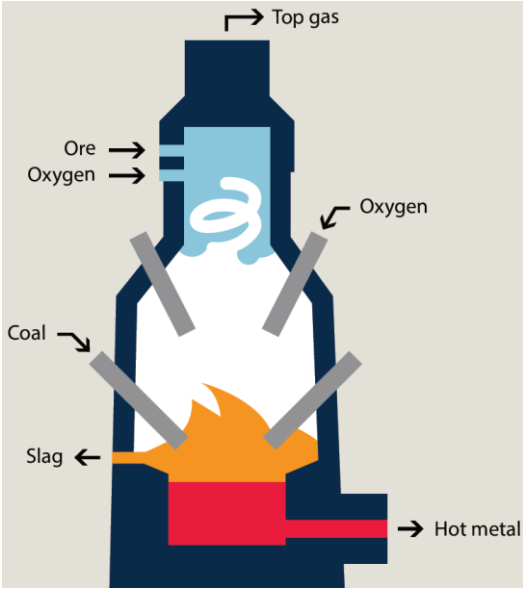

Figure 1: Schematic of the HIsarna process

The thermodynamics software FactSage was used to estimate the effects of the fluxing. The composition of the mixtures can be found in Table 1.

Table 1: Composition (wt%) of ore mixtures used in Factsage; (1): 100% iron ore, (2): 95.8% iron ore, 2.5% limestone and 1.7% dolomite, (3): 95% iron ore and 5% LD-Slag

	1	2	3
Fe_2O_3	88.90	85.12	84.35
Fe_3O_4			1.04
FeO	1.07	1.02	1.13
SiO_2	3.46	3.35	4.01
Al_2O_3	1.42	1.37	1.46
CaO	1.39	1.33	3.42
MgO	0.51	0.49	0.85
MnO	0.82	0.79	1.02
P_2O_5	0.048	0.046	0.126
TiO_2	0.63	0.60	0.66
$CaCO_3$		3.44	0.10
$MgCO_3$		0.76	

Results are visualised in Figure 2. The figure shows that the use of fluxing agents pre-mixed with the iron ore should result in better melting and fluxing behaviour in this part of the reactor. Specific attention will need to be paid to the behaviour of elements such as phosphorus and vanadium from the LD-slag, as it is not clear in

advance how these components would distribute over the hot metal and slag. It is noted, though, that the impact of phosphorus from the LD-slag is expected to be limited, as the HIsarna process results in a lower phosphorus hot metal than blast furnace hot metal, based on the same input materials.

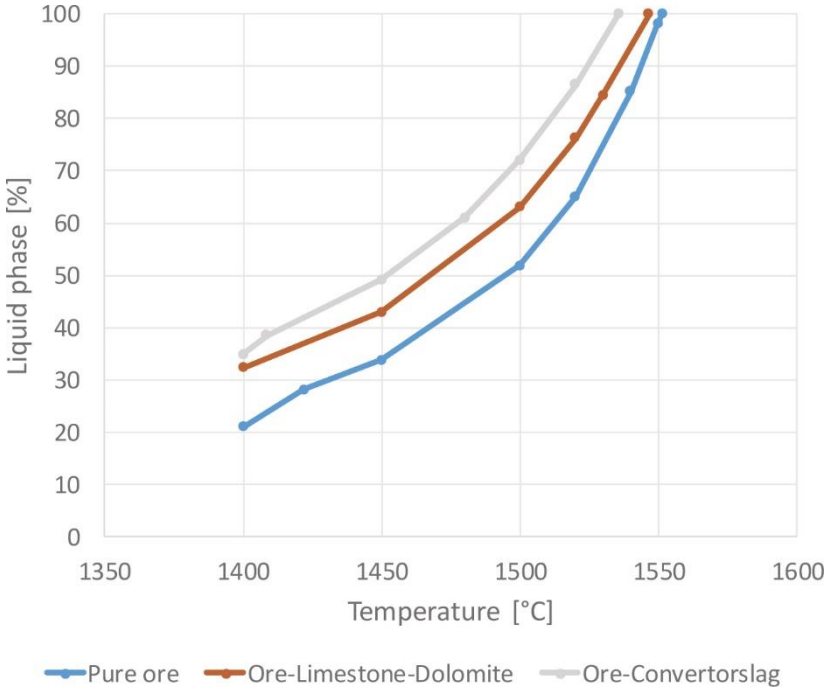

Figure 2: Liquid slag phase for different mixtures calculated using Factsage

Experimental procedure

Slag from the LD-plant of Tata Steel in IJmuiden was ground and screened to a size fraction 0-3 mm. 100 tonnes of material was prepared. The LD-slag was pre-mixed with iron ore at a rate of 5% LD-slag per tonne blend. Note that the upper limit of the amount of LD-slag that can be used in the blend will be determined by the raw material qualities, and the targeted slag chemistry. The blend was subsequently dried using the HIsarna pilot plant ore dryer. This means that around 2000 tonnes of ore-LD slag blend was prepared. This blend was used to fully replace the standard iron ore over a period of three test runs, totalling around 20 days of hot metal production.

Results

It was found that the HIsarna process behaviour and control was similar for both ore mixtures. However, differences in slag and metal composition were observed, see Table 2. For example, the P level in the Hot Metal (~ 0.02%) increased when LD-slag was used, however it was still significantly lower than in typical blast furnace metal (~ 0.05-0.10%). This is related to the higher FeO_x level in HIsarna slag (4-5 wt%) as compared to regular blast furnace slag (~ 0.3 wt%).

Table 2: Average HIsarna slag and metal compositions for test runs with two different ore feed blends; Note the reported Fe_{tot} in the slag is present as FeO_x

	Limestone / dolomite blend	LD slag blend			Limestone / dolomite blend	LD slag blend
Hot Metal	wt%	wt%		Slag	wt%	wt%
C	4.3	4.0		B2 [-]	1.16	1.19
S	0.082	0.088		CaO	38.6	38.2
P	0.016	0.025		SiO_2	33.2	32.0
V	0.0079	0.012		MgO	5.5	5.2
Mn	0.076	0.082		Al_2O_3	12.7	12.5
Si	< 0.01	< 0.01		Fe_{tot}	3.5	3.7
				P_2O_5	0.11	0.22
				V_2O_5	0.064	0.14

It is noted that further studies/trials will be needed to better understand and further optimise the partition of elements (such as P) in the HIsarna hot metal / slag system. Note that an additional benefit of using LD-slag as flux, is that a significant part of the Fe units in the LD-slag can be recovered.

Conclusions

It was demonstrated that LD-slag can be successfully recycled using the HIsarna process. By recycling the LD-slag through this route, the value increases: a significant part of the Fe units contained in it will be recovered, whilst the need to introduce fresh limestone, dolomite or burnt lime to the process is reduced. In addition, the slag from the HIsarna process has the potential to be used for higher value applications, such as cement, in a similar manner as granulated blast furnace slags.

Acknowledgements

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