Experimental investigation into the reduction of MnO using a thermal hydrogen plasma

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Abstract: By transforming hydrogen gas into hydrogen plasma, a more potent reactant is obtained, that can be used to reduce oxides otherwise too stable for hydrogen gas. This was demonstrated through an experimental campaign were MnO is reduced to metallic manganese in a purpose-built reactor designed for experiments with a reducing plasma.

1. Introduction

The production of metals is responsible for considerable CO_2 emissions each year. The major contribution comes from the traditional reductant, fossil carbon. Meaning, even if the electrical grid was completely decarbonised, significant emissions from the metallurgical industry would remain.

For many metallurgical processes, carbon can be replaced with hydrogen (H_2), which will result in the formation of water (H_2O) rather than CO_2 [1]. But for many processes this is not feasible because of the chemical stability of the oxides, an example being MnO. Transforming H_2 into a more reactive hydrogen plasma makes it possible to reduce more stable oxides [2].

Previously a purpose-built reactor for carrying out reduction experiments with hydrogen plasma was built [3], [4]. This work is a continuation where a comprehensive study into plasma-based reduction of MnO is performed. Detailing what conditions are most favourable for the formation of metallic manganese during hydrogen plasma reduction.

2. Methods

This experimental work was carried out in a purpose-built reactor intended for experiments utilising reducing hydrogen thermal plasmas. The main components of the setup is a water-cooled reactor chamber, a 500 A plasma torch with a pencil shaped tungsten cathode and copper anode/nozzle, and a water-cooled copper crucible. The reactor can switch to using the copper crucible as the anode to operate in a transferred arc mode. Furthermore, the reactor is equipped with a camera aimed at the crucible, which provides a video feed during the experiments.

Table 1. Compositions of the slag compositions that was investigated for MnO reduction in this work.

Slag designation	Slag composition / wt%		
	MnO	SiO_2	Al_2O_3
Slag 1	100	0	0
Slag 2	60	40	0
Slag 3	41	48	11
Slag 4	77	23	0

The setup was used to reduce slags taken from the MnO – Al_2O_3 – SiO_2 slag system, see Table 1. In some experiments 15% metallic iron was added to the raw material to improve the reduction conditions. Each experiment used between 500-700 g of material, depending on density, which corresponds to a full crucible. A total of 10 experiments were done.

After reduction with hydrogen plasma, samples were prepared for analysis using EPMA to look for formation of metallic Mn and quantify the Mn content of the FeMn phase.

3. Results and discussion

Reduction of slag 1, which was comprised of pure MnO, was challenging due to the large temperature gradients in the setup. Establishing a significant melt layer was not possible, instead most of the sample would evaporate. This was the case both with transferred and non-transferred arcs. Operation of the reactor was smoother with slag 2, slag 3 and slag 4 as these slags melt at lower temperatures.

The first part of the series was done with the torch operating a non-transferred arc mode. Slag 4 yielded the highest amount of metallic manganese, where a metal phase containing 15% Mn was generated. Due to the good performance of this composition, it was also tested with a transferred arc. The slag was sufficiently conductive for the arc to strike the molten slag and conduct through it, rather than striking the rim of the crucible. As a result, it is suggested that a significant amount of heating occurred due to resistive heating in the slag, which helped counteract the heat loss through the crucible.

4. Conclusions

Production of metallic Mn using a hydrogen plasma has been demonstrated in a purpose-built reactor for experiments with reducing plasmas. To find the optimal conditions for reduction, several raw material compositions were investigated with transferred and non-transferred arcs, as well as with and without the addition of metallic iron.

References

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