Arc physics in hydrogen plasma reduction of iron ore

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Abstract: Hydrogen plasmas are being applied to convert iron ore to iron to reduce the substantial carbon emissions from iron and steelmaking. A computational model of an argon-hydrogen arc that includes demixing and the production of metal vapour is being applied to optimise the arc plasma parameters. The predictions of the model for a range of arc currents and argon-hydrogen mixtures are presented, along with experimental results.

1. Introduction

Iron and steel production is responsible for 7% of global CO_2 emissions, mainly because of the use of coke and natural gas as the reducing agents in the conversion of iron ore to iron. The reduction of high-grade iron ore pellets using hydrogen gas in the direct reduction of iron (DRI) process has been demonstrated. However, most of the world's iron ore reserves are unsuitable for DRI. An alternative process, hydrogen plasma smelting reduction (HPSR), that uses a hydrogen arc plasma to reduce iron ore, is being developed [1,2].

Hydrogen arc plasmas differ significantly from the argon arcs widely used in thermal plasma applications such as arc welding. The hydrogen arc is hotter, more constricted, less stable, and has a higher voltage. To improve stability and reduce voltage requirements, arcs in mixtures of argon and hydrogen are generally used. The arc is also affected by the iron vapour from the molten regions of the anode.

2. Methods

A computational model that solves the coupled partial differential equations describing the conservation of mass, momentum energy and electromagnetic equations has been developed. The model is complemented by two additional equations that solve for the mass fraction of hydrogen and iron vapour, with diffusion treated by the three-gas combined diffusion coefficient method [3]. The model assumes local thermodynamic equilibrium and uses 2D axisymmetric geometry. The electrodes are included in the computational domain, with internal boundary conditions accounting for the sheath effects [4].

Experiments performed using a small-scale arc reactor, with graphite cathode and iron oxide anode, and predictions of a COMSOL computational model of the arc and electrodes that neglects demixing (the separation of gases driven by diffusion) and metal vapour, are used to complement the results.

3. Results and Discussion

Initial results obtained using an argon-helium mixture with a conical tungsten cathode and an iron anode are shown in Figure 1. The temperature is predicted to reach about 17 000 K in the arc and 2300 K in the anode, which is above the melting point of iron (1810 K). Demixing leads to a strong concentration of helium near the arc axis. Iron vapour is produced from the molten anode and is swept outwards by the plasma flow, which is downwards from the cathode to the anode and then radially outwards.

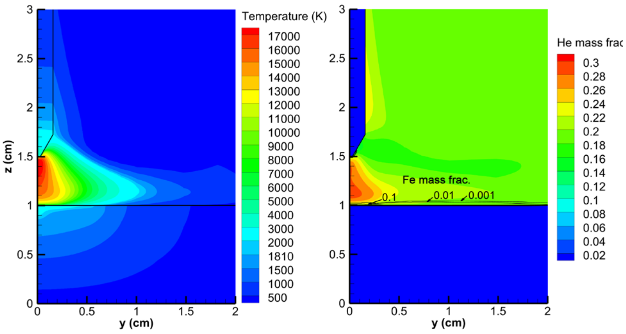

Fig. 1. Temperature, and helium and iron vapour mass fractions, in a 150 A, 5 mm arc in a mixture of 30 mol% (81 wt%) Ar and 70 mol% (19 wt%) He.

Initial experiments demonstrate that iron oxide is reduced by the argon-hydrogen arc. Computational modelling results for various arc currents, argon-hydrogen ratios, arc lengths and cathode shapes are being used to optimise experimental parameters. Demixing leads to the concentration of hydrogen near the arc axis, increasing the transfer of heat and hydrogen species to the molten pool [6]. On the other hand, the iron vapour emanating from the molten pool of iron oxide decreases the heat flux because it increases the electrical conductivity of the plasma at low temperatures, broadening the arc attachment region.

4. Conclusion

Optimisation of the arc parameters is critical to the efficient reduction of iron oxide using a hydrogen plasma in HPSR. For example, the effect of demixing, which increases heat and hydrogen flux to the iron oxide anode, must be balanced against metal vapour production, which has the opposite effect.

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References

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