OBSERVERSHIP REPORT

Manufacture of ferro alloys — silico-manganese and ferro-manganese

Prepared by Harshdeep · Focus: the pyrometallurgical chemistry of carbothermic reduction

I visited a ferro-alloys plant that produces silico-manganese (SiMn) and high- and medium-carbon ferro-manganese (HCFeMn and MCFeMn) at a scale of roughly 2 to 2.5 lakh tonnes per year. I was shown the route from raw-material handling through the submerged arc furnace to casting and dispatch, together with the laboratory. This report focuses on the chemistry.

The chemistry of carbothermic reduction

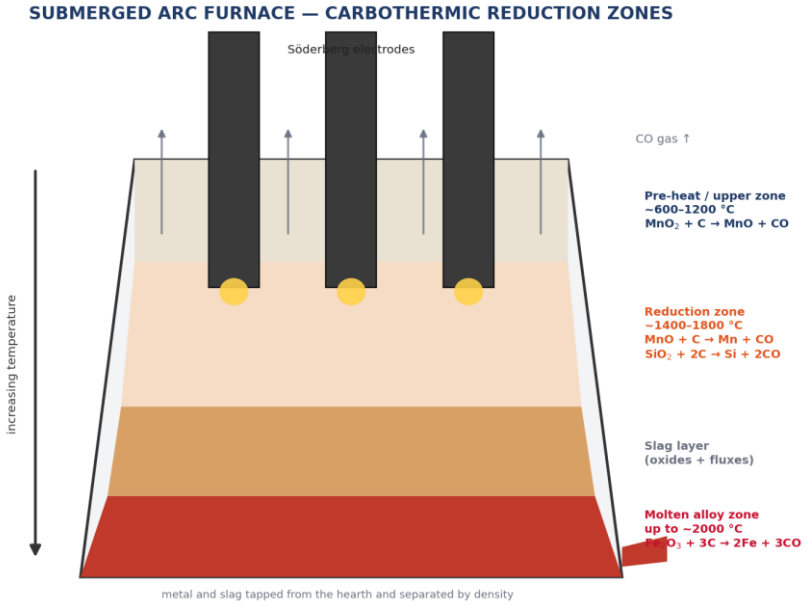
Ferro alloys are made by reducing metal oxides with carbon at very high temperature. This is pyrometallurgy, so the driving change is a set of high-temperature redox reactions rather than solution chemistry, and pH does not apply. The manganese ore is mainly manganese oxides, and the reductant is carbon supplied as coke and coal.

Reduction happens in stages as the burden descends and heats. The higher oxide is reduced first, MnO2 + C → MnO + CO, and the MnO is then reduced to the metal, MnO + C → Mn + CO. Iron oxide in the ore is reduced in the same way, Fe2O3 + 3C → 2Fe + 3CO. For silico-manganese, silica from quartzite is also reduced, SiO2 + 2C → Si + 2CO. Silica is harder to reduce than manganese oxide, so it needs the hottest part of the furnace, and controlling how much silicon is reduced is how the plant sets the silicon content of the alloy, usually 14 to 17 percent in silico-manganese.

In every reaction carbon is oxidised while the metal oxide is reduced, and carbon monoxide gas is released. These reactions are strongly endothermic, which is why so much electrical energy is needed, about 3,800 to 4,500 kWh per tonne. Dolomite and limestone are added as fluxes. They react with unwanted oxide impurities such as silica and alumina to form a slag of lower melting point that floats on the denser molten alloy. Because the alloy and the slag differ in density they separate cleanly and are tapped and skimmed apart.

The submerged arc furnace

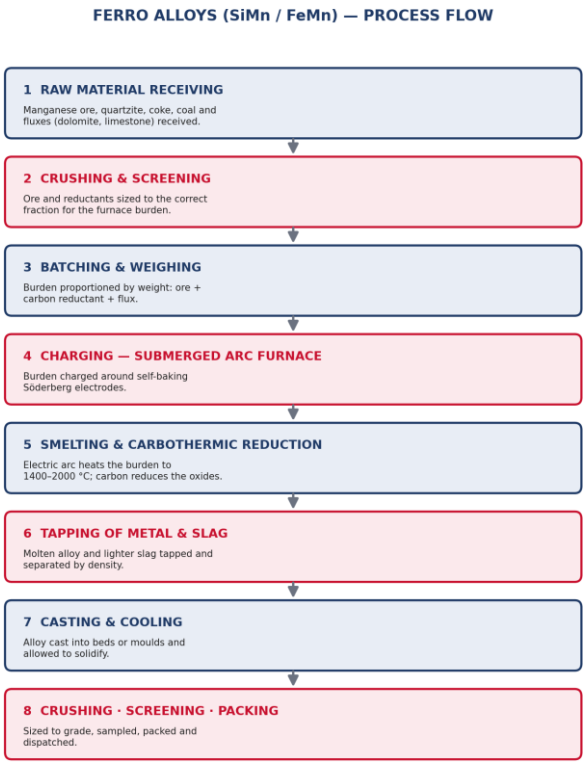
The reactions take place in a submerged arc furnace. Three carbon (Söderberg self-baking) electrodes are lowered into the burden and a very large electric current passes through them, striking an arc that heats the charge to between about 1,400 and 2,000 degrees Celsius. Because the electrode tips are buried in the burden, the heat and the escaping carbon monoxide are trapped within the charge, which makes the process efficient. As the burden sinks it passes through zones of rising temperature: pre-heating and first reduction near the top, full reduction to metal in the middle, and molten metal collecting in the hearth at the bottom. The diagram shows these zones with the main reactions.



Reduction zones inside the submerged arc furnace, with the main reactions at each level.

The manufacturing process

The sequence I observed is set out below. The raw materials are crushed, screened and weighed into a burden of ore, carbon reductant and flux, which is charged into the furnace. After smelting and reduction the metal and slag are tapped, the alloy is cast and cooled, and it is then crushed, sized to grade, sampled and packed.



Flow of the ferro alloys process observed during the visit.

Quality-control chemistry

The laboratory controls the composition of the alloy. Samples are taken at each tapping and from the finished product. An X-ray fluorescence analyser and an optical emission spectrometer measure the metal content, so manganese, silicon and iron can be held to grade, which for silico-manganese is about 60 to 65 percent manganese and 14 to 17 percent silicon. A carbon-sulfur analyser measures carbon and sulfur, because carbon sets the grade and sulfur and phosphorus are unwanted impurities. Particle size is checked by sieve analysis and moisture by drying, and the slag chemistry is monitored so that impurity removal stays on target.

Environment and energy

The process makes large amounts of carbon monoxide gas and dust, so it is fitted with bag filters and fume extraction, and the furnace gas can be captured for reuse. Slag is recycled where possible rather than dumped, and waste heat is recovered. Because the reduction is so energy-intensive, high-efficiency transformers, power-factor correction and optimised furnace operation are used to keep electricity use down.

What I learned

The plant showed me redox chemistry at industrial scale. Every product comes from carbon reducing a metal oxide, and the whole operation is really about controlling temperature, the carbon balance and the slag in order to hit an exact alloy composition. Seeing a reaction I had only written as an equation, $MnO + C \rightarrow Mn + CO$, actually running inside a furnace made the chemistry concrete and strengthened my interest in chemistry and materials.