

### Single-Step Ironmaking from Ore to Improve Energy Efficiency

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Current blast furnace technology is a two-stage ironmaking process that requires that iron ore concentrate first be formed into pellets, fired at 1260°C, cooled, transported to the blast furnace, and then re-heated to approximately 1500°C to produce pig iron. This heating, cooling, and then re-heating wastes a great deal of energy, which would be saved if the ironmaking process had only a single heating step. Kobe Steel's ITmk3 process is intended as a replacement for blast furnace processing that produces "pig iron nuggets" directly from cold-pelletized iron ore concentrate in a single stage of heating. It is therefore more energy-efficient than the current technology. Iron nuggets are produced by combining iron ore concentrate with a reducing agent (finely ground low-sulfur coal), a binder, and a flux to form pellets. These pellets are then heated to approximately 1400 – 1500°C in a rotary-hearth furnace. Upon heating, the pellets self-reduce to molten iron and molten slag, which separate from each other to form a metallic pig iron nugget and a slag drop. Upon cooling, the slag separates cleanly from the metal nugget. The objective of this project was to determine how the transformation from powdered iron oxide to metal+slag occurs, to examine how the transformation is affected by temperature and processing time, and to determine the optimum conditions for producing iron nuggets as a function of temperature.

This project determined that, contrary to what had been believed by the developers of the ITmk3 process, the iron oxides did not directly react with the coal to produce pig iron in a single step. Instead, the transition consisted of the following stages:

1. Coal volatiles reacted with the iron oxides to produce "Direct Reduced Iron" (DRI)
2. Silicate gangue, coal ash, flux, and FeO melted to produce a slag, while the direct reduced iron began to melt due to dissolving excess carbon from the coal. This produced a mixed slag/metal product, "Transition Direct Reduced Iron" (TDRI)
3. The TDRI then fully separated into a liquid pig iron drop and a liquid slag drop. Upon cooling, this produced a pig iron nugget and a cleanly-separated slag nodule.

The time needed for this transformation was a strong function of temperature, with times ranging from over 40 minutes at 1400°C, to approximately 10 minutes at 1500°C. It was determined that industrial-scale rotary-hearth furnaces were producing nuggets with highly variable quality due to some pellets being heated more than others, with the cooler pellets having insufficient time to complete the transformation to iron nuggets. Uniform heating in the furnace is therefore key to maintaining satisfactory nugget quality.