Steel for the Non-Metallurgist

An Online Continuing Education Course for Engineers

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Steel for the Non-Metallurgist

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Introduction

Steel offers a unique juxtaposition in today's society. It is one of the most highly engineered products available, with numerous variations suitable for an extremely wide range of applications, and it is cheaper per pound than a bag of potatoes.

Steel is consumed yearly in the millions of tons. Much of this steel is recycled, but as products and structures are built with increasingly long service lives, the steel demand still greatly outweighs what is being recycled every year.

Steel mills are a critical backbone of the industry, and the origin points to many complicated supply chains. Steel products saturate everyday life, be it cars, appliances, buildings, computers, tools, or even silverware.

I. The History of Steel Mills

Steel and the Second Industrial Revolution

Smelting iron was so important to human history that it was even given its own era: the Iron Age. A follower of the Stone Age and the Bronze Age, the Iron Age saw critical progress in tool and weapon making. Slow advancements through the Middle Ages and early 1800s produced cast irons. However, it wasn't until James Beaumont Neilson's patented "hot blast" technique for producing pig iron that exponential growth in production and technology occurred.

This dramatic growth set the stage for steel to become the next monumental development in the long history of ironmaking. Pig iron is the product of removing oxygen from iron ore and adding small amounts of carbon. To form steel, the carbon content of pig iron, which is about 4-5%, must be reduced to less than 2%. Henry Bessemer and his Bessemer converter accomplished this. Air was blown through molten pig iron to react with the excess carbon, producing off-gasses such as carbon monoxide and carbon dioxide.

Sir Charles Williams Siemens and the Siemens-Martin process worked in conjunction with the Bessemer process to greatly lower the cost of production and improve the quality of steel. In the late 1800s, the usage of iron and steel began to flip. The Eiffel Tower, built in 1889, was one of the last large-scale structures built out of iron. In 1893, the Ferris wheel for the Columbian Exposition in Chicago was one of the first major steel structures to be built. Steel continued to dominate through the 1900s.

Steel in the 20th Century

Open-hearth furnaces produced steel cast into ingots, producing blocks and bars. These were subsequently reheated and rolled into slabs, blooms, or billets, again reheated to be rolled into finished products.

In the 1950s, continuous casting was introduced. Instead of pouring molten steel into a mold, the molten steel was cast directly into semifinished billets, bars, or slabs. Continuous casting improved yield, which lowered the amount of energy consumed compared to ingot casting. Continuously cast steel was also more chemically homogenous, less segregated, and had fewer surface defects.

In 1969, Nucor's first mini mill started production in Darlington, South Carolina, revolutionizing steel production.

Steel Today

Continuous casting produces over 70% of the steel used today. Continuously cast sections include billets, blooms, slabs, and strips.

Two types of steel mills with continuous casters are integrated and mini-mills. Integrated mills create steel from iron ore, coke, and limestone. Mini mills use electric arc furnaces to melt scrap.

Steelmaking is a worldwide activity. The United States, India, Japan, Russia, South Korea, China, and fourteen other countries produced tens of millions of tons of steel in 2021. China is far beyond any other country – China's production is about twelve times that of the United States. (1)

The push for "green steel" will spark fundamental changes in steel production. Industry leaders are devising ways to reduce the use of fossil fuels in steelmaking, promising fossil-free steel production around 2030.

II. Steelmaking

Steel Products

Steel applications require steel to be in a variety of shapes and sizes. Mills offer various products to meet demands, and the categories are broken down below.

1) Long products
    a) Bar products
        i) Angles
        ii) Channels
        iii) Rounds
        iv) Rebar
        v) Wire rods, etc.

b) Beam products
    i) I-beams
    ii) H-pile shapes
    iii) Channels
    iv) Angles, etc.
2) Flat-rolled products
    a) Strip
        i) Sheet
        ii) Plate
    b) Plate

<u>Integrated Mills</u>

Integrated steel mills are the juggernauts of the steel industry in more ways than one. Not only are they enormous in scale – in both production and physical size – but once the blast furnace begins to output pig iron, the steelmaking process must continue or risk damaging the blast furnace.

Many well-known names in steel have integrated mills: ArcelorMittal (now domestically associated with Cleveland Cliffs), US Steel, SSAB, Tata Steel, and more.

Integrated mills require vast amounts of land and resources. They are often located near lakes and rivers to receive iron ore and coal by barge. US Steel Gary Works spans almost seven miles along the coast of Lake Michigan; it has its own rail system and roads, and years ago, it had its own hospital. The byproducts of the coke ovens even powered the city of Gary for some time.

Figure 1: Blast furnace C at Cleveland Cliffs Burns Harbor, formerly ArcelorMittal. Photography by Viktor Matcha.

Water access is vital not only for material transportation but for many of the processes that take place at integrated mills. Things must be cooled, and where things must be cooled, water is essential. Large mills can use more than millions of gallons per hour. The water is collected, cleaned, and reused or returned to its source cleaner than it was taken.

The integrated steelmaking process begins with the blast furnace. Blast furnaces are easy to spot far off the steel mill's campus. These tall stacks tower over nearby infrastructure; enormous pipes, tubing, scaffolding, and giant conveyors make them easily distinguishable, along with the seemingly ever-present clouds of steam wafting into the surrounding air. Iron ore, coke, and limestone are dumped into the top of the blast furnace via conveyor, where they meet a hot blast of air. Temperatures inside of the blast furnace can reach over 2000˚F. As the iron ore melts, it travels downward to the bottom of the furnace, creating a cycle that allows the furnace to operate continuously. Raw materials enter at the top, and molten pig iron is tapped, or emptied, at the bottom.

To withstand the scorching temperatures, blast furnaces are lined with refractory bricks. These bricks hold up well to intense heat, but as a ceramic, the bricks are brittle and sensitive to extreme temperature changes. This is another driving force for blast furnaces to operate continuously: when idled, the thermal contraction in the bricks can be so large that they crumble. Partially relining a blast furnace can cost millions of dollars. Fully relining a blast furnace can cost upwards of $100 million dollars.

Figure 2: Burns Harbor blast furnace C casting house. Photography by Viktor Macha.

The pig iron is poured from the bottom of the blast furnace into a torpedo car, aptly named because they are shaped like a torpedo. These vessels hold the temperature of the molten pig iron as it is transported via rail to the next process.

Pig iron, named because when cast into ingots, it looked like suckling pigs, has about 4-5% carbon content.

To reduce the carbon content, the pig iron is transported to the basic oxygen furnace (BOF), also called a converter, in quantities around 300-400 tons. In the BOF, oxygen is blown through a lance and the molten iron at supersonic speeds to react with the excess carbon. This reaction raises the temperature inside the BOF, requiring the outside of the vessel to be water-cooled.

During this process, a layer of slag forms on top of the molten steel. Slag contains impurities, largely metal oxides, and it floats and protects the steel from further oxidation. From this point on, it is vitally important to protect the steel from the atmosphere – at such high temperatures, the reaction rate to form iron oxides is extremely accelerated.

Final alloy additions are made once the pig iron has been converted to steel. Some steel mills perform vacuum degassing to remove hydrogen and nitrogen, which are otherwise difficult to remove. One ladle signifies one steel heat; all products produced from heat will have the same chemical content.

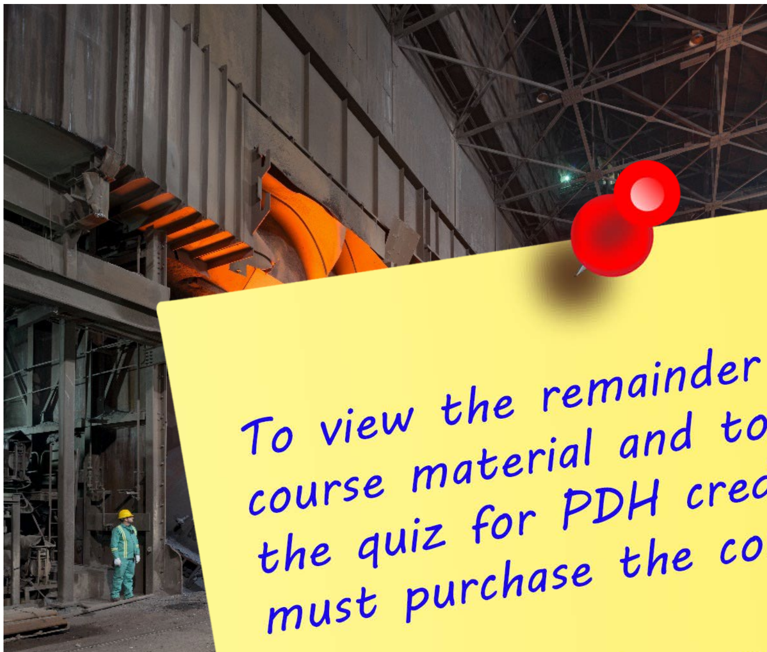

Figure 3: Burns Harb

Now ready to cast, the steel is brought to the continuous caster in a ladle. The ladle bottom pours into a tundish, swimming pool-sized reservoir t d the molten steel. ws the continuous continuously; once urs into the caster, ladle time to arrive completely.

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t vertical machine stories. At the entry nozzle that steel from the een, but all of neath the floor. s machines are oled rolls formed shell

hard at work, but n come into view, indi from a vertical positi horizontal position. S eyebrow-searing heat like glow of the steel e the rolls.

What is invisible to onlo is a critically important, extremely sensitive process. The caster is made from a copper mold. Mold powder is added to lubricate the delicate steel shell as the caster gently fluctuates up and down, encouraging the steel to travel downward. The walls are cooled by water, and the shell thickens enough to become stable as the steel exits the caster.

Figure 4: The continuous caster at Tata Steel Port Talbot. Photography by Viktor Macha.