The Hot Rolling Process

The primary function of the Hot Strip Mill is to reheat semi-finished steel slabs of steel nearly to their melting point, then roll them thinner and longer through 12 successive rolling mill stands driven by motors totaling 77,000 hp, and finally coiling up the lengthened steel sheet for transport to the next process.

The Hot Mill rolls slabs weighing up to 30 tons between 30” and 74”. Steel slab 8 to 9 inches thick and up to 36 feet long is rolled into strip as thin as 1/16 inches and up to a half-mile in length. Coils are produced with a 30” inside diameter (‘eye’) on one of two coilers, with outside diameter limitations of 72” and 74”, corresponding to 850 and 1000 pounds-per-inch-width (PIW), respectively. The mill supplies coil for each of CSI’s remaining operations, as well as a finished product for shipment directly to CSI’s customers.

Most material is transported out of the mill area by an automated coil handling system, though some skelp for the Pipe Mill is staged toward the east end of the mill bay until it is cool enough to load onto rail cars.

Reheating

Critical to the Hot Strip Mill is its walking-beam reheat furnace, state-of-the art equipment that replaced and now outperforms three older- (pusher-) style furnaces. Nominally rated to produce 270 tons-per-hour, improvements in efficiency and some sacrifice in slab temperature uniformity enable extended production rates 25% above design. Heating this much steel from room temperature to 2200-2400 degrees Fahrenheit consumes around 10 million cubic feet of natural gas each day.

As slabs are assigned to orders, schedules are written and material is staged with rail-cars and overhead cranes in the slab yard at the west end of the Hot Strip Mill. Slabs are placed, one at a time, on a roll line. The slab’s dimensions and weight are confirmed as it is positioned in front of the charge door on the south side of the furnace. When space is available in the furnace, large electro-mechanical ‘pusher arms’ engage to move the slabs into the furnace.

Once inside, the slabs are supported about eight feet off of the furnace floor by water-cooled, refractory-coated pipes called ‘skids’. To minimize the cold spots (‘skid marks’) left in the slab, the skid spacing changes approximately two-thirds of the way through the furnace. Two independent sets of skids, one fixed, one walking, take turns supporting the slab as it is walked through the furnace by a massive sub-frame energized by a pair of large hydraulic cylinders.

The interior of the furnace is 38’9” wide, fifteen feet from floor to ceiling, and 142’ long. It is divided into eight zones for temperature control: preheat, top-and-bottom; heating, top-and-bottom; and soak, top-and-bottom, east-and-west. The preheat and heating zones combust a mixture of natural gas and preheated combustion air with massive burners on the side walls of the furnace, both above and below the skids, to heat the slab nearly to its discharge temperature.

Much of the preheating of the steel is achieved by the hot exhaust gases rushing past the slabs on the way to the ‘recuperators’ above the charge door. Whatever heat is left in the exhaust gases preheats the incoming combustion air to over 1000° F in these massive heat-exchangers. Conversely, in the heating zone the steel is primarily heated by the glowing-hot furnace walls. In the soak zone, numerous smaller burners seek to maintain a uniform temperature within the zones to equilibrate any cold spots in the slabs. Refractory dividers help to physically distinguish the zones, and thermocouple temperature sensors throughout the furnace interact with the automatic burner control systems to maintain the target temperatures in each zone.

Complex computer models calculate the targeted roughing mill exit temperature to obtain a furnace discharge ('drop-out') aim temperature. Estimating the temperature profile through the thickness of each slab in the furnace on an ongoing basis, the computer aids the operator in selecting the production rate and zone set-points that will maximize production of steel slabs uniformly heated to as close to the target temperature as possible. After the rolling process begins, as the steel exits the roughing mill, its temperature is fed back to the furnace, updating the computer models and informing the Heater as to the temperature uniformity.

When the slab reaches the 'discharge door' at the exit end of the furnace, and the computer has determined that the slab has been sufficiently heated, the door opens and massive 'extractor arms' reach beneath the slab, lift it off of the skid supports, and draw it out of the furnace. The east and west extractors can act independently of one another to remove double-charged slabs one-at-a-time, or in conjunction to extract longer slabs. The intensely hot slab is placed on a roller table which carries it into the roughing mill.

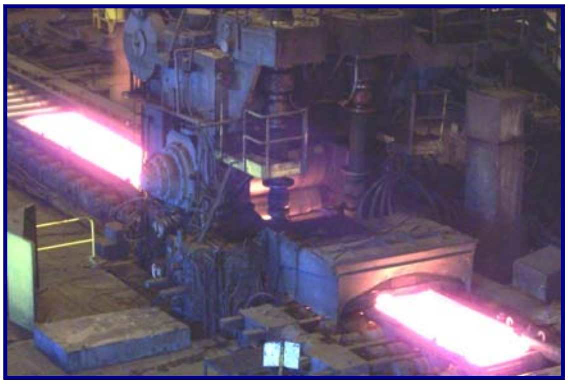
Descaling

After exiting the reheat furnace, the slab passes through a descaling unit, an enclosure employing two pairs of spray headers that blast the intensely hot slab with 1,500 psi pressurized water to remove the 1/8-inch thick layer of oxidized iron that forms at the surface of the slab in the oxygen-rich atmosphere of the reheat furnace. Shortly after descaling, a (relatively) small 2-hi rolling mill called a scalebreaker reduces the slab's thickness by about one inch to break up any scale that remains. Just before the next reduction pass is taken, 'sweep sprays' clean away any loosened scale that remains on the slab surfaces. The transfer bar will be descaled twice more during roughing, immediately prior to the third and to the last rolling operation, to remove the scale that has grown back over the three minutes or so that it spends in the roughing mill.

Roughing

The roughing mill is made up of six independent rolling mill stands, the last four of which incorporate small vertical rolling mills called edgers. Slabs heated in the furnace until they glow bright orange-yellow are rolled through one stand at a time to produce so-called transfer bars suitable for finish rolling. High-pressure water-jet nozzles clean the oxidized iron, or scale, from the surface along the way.

As the transfer bar exits the last roughing mill stand, the thickness of the leading edge of the bar is estimated. Similarly, a pyrometer measures the temperature profile of the bar from head to tail and a special camera photographs both ends. Depending on the gauge, width, and grade of the product to be rolled, the average temperature of the bar as it exits the last roughing mill normally ranges from 1900° to 2100° Fahrenheit. This data is collected in anticipation of finish rolling. Computers immediately begin calculating the speeds and gaps for threading the six finishing mills, which will roll the steel in tandem with one another.



The workhorse roughing mill has 135" wide rolls for rolling 'broadside' (as the first roughing mill is commonly called) to make a slab wider. A 5,000 hp motor drives 42"-diameter work-rolls through 28:1 gears to reduce the slab's thickness by as much as 2-½".
The last four roughing mills each incorporate edgers for width control and roll the bar from five to six inches thick incrementally down to around an inch and a quarter, depending on the customer's ordered width, gauge, and steel grade. As mentioned previously, the third and fifth roughing mills each have high-pressure descaling headers operating at 1,500 psi. The individual roughing mills are spaced increasingly further apart to accommodate the lengthening of the transfer bars as they are rolled thinner and thinner.

Edging

At the very high temperatures at which the steel is rolled in the roughing mill, it is very plastic and 'flows' easily like cookie dough beneath a rolling pin. Consequently, as the slab is reduced from eight to nine inches thick to the final bar thickness of one to one and one-half inches, bars tend to spread width-wise by a few inches at their extremities, and by as much as an inch through the body. The edgers serve to hold a uniform width through the bar's length, and are powerful enough to squeeze the bar as much as an inch narrower than the slab's original dimension.

Descaling

Between the Crop Shear and the first Finishing Mill stand sits the #2 ScaleBreaker, which is tasked with the final scale removal operation. Sprays above and below the transfer bar blast it with 1,500 psi jets of water to break

up the scale that has re-formed since the descaling operation at the entry of the last roughing mill, as well as any scale that has persisted through earlier descaling operations. After descaling by the low-pressure headers, the bar is pinched by a pair of pneumatically-actuated rolls to mechanically loosen any remaining scale, which, as the processing temperatures cool off, becomes increasingly sticky even as it returns ever more slowly to the surfaces of the still red-hot steel. Finally, a pair of high-pressure headers operating at nearly 3,000 psi makes a final pass at both surfaces of the transfer bar shortly before it enters F6 for finish rolling. As with the roughing mill's descaling system, for some thinner-gauge, wider, and/or stiffer products, the low-pressure header is disabled to conserve heat for rolling.

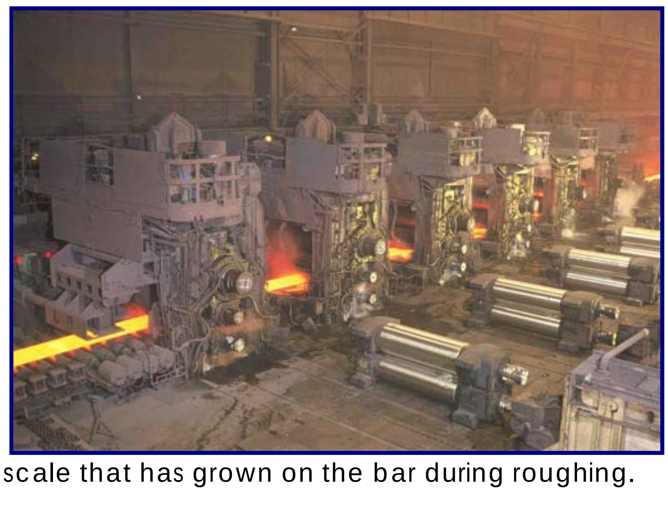
In part because further descaling is not particularly practical once finish rolling begins, the #2 Scale Breaker is the last opportunity to remove oxidation before the finished hot-rolled strip is coiled. Typically, the descaling system in the Hot Strip Mill is very effective at removing primary (from the furnace) and secondary (regrown during roughing rolling) scale.

Cropping

Because a square head-end is critical to properly threading the finish mills and the downcoilers, and because an uneven tail can bruise work-roll surfaces or cause threading problems for the next production process, the head- and tail-ends of nearly every transfer bar are cropped by a pair of large steel drums each with a shear-blade extending along its length. With the bar crawling along the roller table at around 100 fpm, sensors detect its position and speed in order to time the crop shear drums to optimize the amount cropped; since transfer bars are over an inch thick, each extra inch of crop-length scraps another 15-30 lbs.

Finishing

CSI's Hot Strip Mill includes six finishing mills, which reduce the thickness of the transfer bar down to the gauge required by the customer or the next process. The rolling speed is set to allow the last stand to perform the final reduction at the finishing temperature, between 1500° to 1650°F, specified to reach certain mechanical properties.



By now, the steel has been rolled into a flat bar as long as 200 feet. In contrast to the roughing mills, the finishing mills roll the transfer bar in tandem, meaning each bar will be rolled through all six stands at once. The hot steel is quite fragile as it is rolled and tension between the finishing mill stands must be closely controlled at very low levels in order to avoid stretching or tearing the strip.

Prior to the finish rolling operation, the head- and tail-ends of the transfer bar will be sheared to square them up, helping to ensure proper threading and tail-out. A final two-stage descaling operation is performed to clean off the scale that has grown on the bar during roughing.

Once the bar is threaded between each successive pair of mills, a free-turning roll on an electro-mechanical pivot called a looper roll engages the bottom of the strip to monitor the tension between the stands. Adjustments are made as necessary to ensure the strip threads properly through each of the mills without looping up and folding over or stretching and tearing apart. The position of each roll is fed back to the finishing mill's sophisticated automation system which, along with information from the load cells that monitor rolling force and from the X-ray gauge measuring final strip thickness, work to smoothly adjust the roll gaps and speeds to maintain stable rolling of strip to the necessary thickness in spite of the temperature variations present in every bar.

Temperature Control

A profound metallurgical transformation in the crystal structure takes place as the material cools, which, depending on the specific chemistry of the material, typically is between 1450° and 1600°F. Additionally, the mechanical properties of the final product respond to some degree to the specific temperature at which the final reducing pass is taken.

Consequently, a finishing temperature for each product is specified and mill automation will adjust the speed of the first finishing mill stand based on its temperature and the extent to which the bar is expected to cool as it makes its way through each stand, in order to allow the strip exiting the finishing stands to meet the target temperature.

Since each transfer bar spends approximately one minute in the finish mill, from head to tail, the temperature of the steel going into the finishing stands will be significantly lower, perhaps 200°F, by the time the tail-end is rolled as compared to the head-end. Consequently, once the first 500 feet of strip has been rolled at the thread speed and a downcoiler has been threaded, the mill begins to accelerate at a 'zoom' rate that had been calculated from the temperature profile of the bar as it exited the last roughing mill. Top speeds as high as 2,700 fpm (30 mph) are reached by the mill automation seeking to maintain the specified finishing temperature throughout the final product. A pyrometer placed after the last stand updates the finishing mill's computer models and allows for the addition of this temperature to strip quality records.

Gauge Control

With the tremendous rolling forces present in a rolling mill, it is not sufficient to simply set the gap between the work rolls to the thickness desired and expect the strip to come out the other side at that thickness. With rolling forces regularly exceeding 3,000 tons in the early finishing stands, the mill housings can be expected to stretch as much as one half inch after the bar enters the bite when rolling wide, stiff, and/or light-gauge products. When setting the roll gaps for threading, it is critical that this factor be compensated for in each of the mill stands; to do so, sophisticated models are used by mill automation to estimate the rolling force for each transfer bar in each stand based on, among other things, the incoming and outgoing thickness, width, steel grade, and estimated instantaneous temperature.

The models employed by the mill automation are updated with the rolling parameters and product measurements each time a new slab is rolled, continually optimized the mills' automation set-ups. Product quality and production yield benefit from scheduling products with similar gauge and grade to roll in succession, allowing automation to deploy the most recently utilized rolling model.

Flatness and Crown

In addition to the degree to which mill stands stretch under rolling loads, as described previously, the rolls will deflect, or bend, under load since they are being forced apart in the middle by the strip but are supported at the ends by the bearings. This deflection is the source of the strip attribute commonly referred to as crown. Strip crown is initiated in the roughing mills and continues through each successive rolling mill stand. Strip crown is measured at the exit end of the finishing mills by a second, scanning X-ray gauge which traverses back-and-forth across the width of the strip as the steel is rolled. The thickness it measures is compared to the thickness measured by the primary X-ray monitoring the center-line gauge through the length of the strip and the difference is then plotted as a product quality record. Typically, the Hot Strip Mill produces material with between 0.001” and 0.003” of crown depending on a number of factors that include the gauge, width and grade of the finished product.

Operators of any rolling mill have a degree of control over the shape of the roll gap by adjusting the screw-downs to increase or decrease the roll force present in that stand, influencing the degree to which the rolls deflect. The last four finishing mill stands, like most modern rolling mills, incorporate hydraulic work-roll bending to give the operators additional control over the shape of the loaded roll gap. In contrast to the other rolling mills at CSI, all of which roll steel at or near room temperature, the plasticity of red-hot steel allows the Hot Strip Mill, by forcing material to flow width-wise, to alter the profile in the strip without introducing shape defects. Operators will adjust work-roll bending in these stands to influence the crown in the final product. The work-roll bending in the final finishing stand is used exclusively to create a roll gap shape that matches the profile of the strip exiting the prior finishing mill to produce a flat, final product.

After exiting the finishing mills, the strip is carried down a succession of more than 260 individually-driven rolls through four banks of low-pressure, high-volume water sprays that cool the red-hot strip to a specified coiling temperature between 1000°F and 1250°F and into one of two downcoilers. Side guides on either side of the run out table seek to keep the strip’s head-end pointed at the coilers; the final section of guides in front of each coiler adjusts to match strip width and features a pneumatic quick-close system that allows the operator to center the strip head-end as coiling begins.

Laminar Cooling

Metallurgically critical to the properties of hot-rolled steel is the coiling temperature, as the coil will cool from this temperature to ambient over the course of three days. Essentially a heat treatment comparable to annealing, the stresses imparted to the steel during reduction from nine inches thick down to ordered gauge are given the opportunity as the coil cools to relieve themselves. Though the steel is continually recrystallizing during hot-rolling, reductions in thickness sometimes in excess of 99% and taking place in less than ten minutes stress the steel considerably; coiling temperature is specified by product metallurgists to harness and manipulate those stress levels in search of optimal mechanical properties.

Product sold as hot rolled and hot rolled pickled and oiled to be laser cut by a customer is coiled at relatively high temperatures to try to relax the steel as much as possible so that parts cut from the coil will lie flat even after residual stresses have resolved themselves around the part’s configuration. Conversely, coiling at a relatively cool temperature allows physical quality steel grades to retain higher internal stress levels and limits the size of the individual crystals and of the carbides that form within and between the crystals; each of these factors contributes to higher strength levels in the finished hot-rolled strip.

Cooling steel 400°F as it rushes past at speeds up to 2700 fpm requires tremendous amounts of water, so a total of 152 spray headers, individually valved and controlled by the automation system, drench the steel from the top and bottom with curtains of water. The computer estimates, based on the thread speed of the strip and target finishing temperature, how much water will be needed to cool the head-end, and the accuracy of this estimate is confirmed by a pyrometer in front of the downcoilers. As adjustment to the number of sprays in use is needed, the computer will turn sprays on and off to meet the targeted temperature through the length of the coil. Since the finishing mills will accelerate once the downcoiler is threaded to continue to make finishing temperature, increasingly more sprays are activated as the steel is rolled in order to compensate for the reduced time it spends on the run-out table.

Up to 75,000 gallons of water are pumped each minute throughout the Hot Strip Mill to cool finish-rolled strip, furnace skids, mill rolls, and coiler components, and to descale transfer bars. All water is recycled through a system of scale/sludge collection pits, through the laminar cooling system, and back to one of the two dedicated cooling towers.

Coiling

CSI's Hot Strip Mill's present configuration relies on two Coilers. Minor differences exist between the two, but both operable coilers begin with a pair of pinch rolls that catch the strip head-end and establish tension across the run-out table and back to the finishing mills. The head-end is deflected by a gate down to the 30" mandrel associated with the coiler and is guided around the mandrel by pneumatically-actuated wrapper rolls linked by aprons.

Once the head-end is all the way around the mandrel, laps begin to build around the mandrel, forcing away the wrapper rolls. Once the head-end is 'cinched' and friction and tension prevent the wraps of steel from slipping relative to the mandrel, the wrapper rolls disengage from the growing coil of steel. After the strip tails out of the finishing mill, the pinch rolls continue to hold back-tension to prevent the coil from unraveling; before the strip tail is pulled through the pinch rolls, the wrapper rolls are reengaged. A hydraulic coil car moves into place beneath the coil, and, after rising up to support the coil's bulk, strips the coil from the mandrel and places it in position for transport to the tagging and automatic bander procedures.

Coil Handling

Coils are removed from each coiler by hydraulic 'coil cars' that set the product down on the platform in the 'hole' where one of the two 'walking beams' cycle back and forth to move coils into position to receive identification and banding. Since the product is still too hot to apply the paper tickets that identify coils throughout the rest of the plant, a pair of 'taggers' employ lasers to burn identifying information onto stainless steel tags affectionately referred to as 'license plates'. These are spot welded to the outside wrap of steel before the band is applied. Slabs that previously were identified by Heat and Cut numbers from the supplier's caster are re-identified as a specific roll item with a six-digit alpha-numeric code.

A second coil car takes the coil from the bander to a rotator outside of the mill building which slowly spins the coil 90° so yet another coil car can take the coil east to the 'lift-and-carry'. Two more (high-speed) coil cars and another lift-and-carry complete the coil's journey either to the conveyor that will take it into Hot Strip Finishing or to the Cooling Pond. In all, the automated system employs ten distinct electro-hydraulic devices each depending on multiple sensors to transport 90% of the Hot Strip Mill's production to the building where the next operation will be performed.