# The Cold Sheet Process

CSI's Cold Sheet Mill is capable of finishing 360,000 tons per year of cold-roll steel up to 60" wide. Its primary function is to restore the formability of the steel from the 'full hard' condition produced during cold reduction at the 5-stand.

Furnaces heat the steel to pre-specified temperatures, typically around 1200 degrees Fahrenheit, that allow the individual iron crystals to re-grow. This heat treatment is known as annealing, and relieves the high stresses imparted to the steel during cold reduction, softening the material and roughly restoring the forming properties that were present after hot-rolling. Certain products, as necessary, are processed at a unit called the "cleaner" prior to annealing to coat the sheet with a protective chemical film, to remove any heavy deposits from the steel, or to prepare the strip in any other way necessary for the heat-treat operation.

The annealed steel is temper rolled to further flatten the product and to stiffen the steel slightly so it will bend uniformly when CSI's customers form it into finished products. The product's final surface texture is also applied here. Many cold-roll products ship after processing at the temper mill, where the coil is inspected, weighed, its length is measured, and it can be coated in oil and split to make customer weight requirements.

## CLEANER

Although the cleaning line once processed every cold-rolled coil prior to annealing, improvements to the sheet cleanliness at the 5-Stand and to the annealing equipment and process have allowed many products to be heat-treated in the 'mill clean' condition. The cleaner pulls strip through a caustic bath that is maintained at temperatures around 200 degrees Fahrenheit. Oil residues from the 5-stand are removed and a thin film of silicate is plated onto the strip to deter the wraps from sticking to one another during anneal. The bath incorporates an 'electrolytic cleaner unit' that applies 7200V in a reverse electro-plating process, attracting oils and iron 'fines' (dust) off of the strip. Rotating brushes scrub both surfaces before the steel is rinsed in water and hot-air-dried.

A small 3-roll leveler, called a flattener, at the entry end straightens out the steel, removing 'coil set'. The head-end of the next coil to be cleaned is over-lapped with the tail of the previous coil and the two are either spot-welded or, for heavier gauges, crimped ('stitched') to one another.


At the exit end, a pair of bridle rolls allow the exit reel to hold the strip under tension while coiling to produce a straight side-wall and prevent the coil from collapsing. Various tension control strategies allow the wind tension to be adjusted as the coil is formed in order to produce a tightly wound coil without contributing to annealing stickers by applying unnecessarily high pressure between the wraps. Coils are upended to an eye-vertical orientation in preparation for the annealing stack, then staged between the cleaner and annealing bases with a crane-operated magnet until they can be incorporated into a charge.

## ANNEALING

CSI's annealing facilities were upgraded with construction of with 20 state-of-the-art bases in 2001. The furnaces use pure hydrogen gas to carry heat from the inner shell to the steel, preventing oxidation and cleaning the steel by volatizing any oil and sweeping away the iron fines left by the 5-stand. The primary function of the annealing process, however, is to heat the steel to a temperature that will restore formability to the stiff, elongated iron crystals, or grains, formed during cold-reduction.

Steel that has been deformed at room temperature, or cold-worked, retains a large amount of potential energy in the form of internal stress between the individual atoms. Further forming of the steel will require much greater forces than was required prior to cold reduction, and is more likely to cross the threshold at which the atomic bonds are broken and the steel cracks. By heating the steel, the atoms are given enough energy to migrate within the crystal structure, with higher temperatures hastening the process. Specifying the temperature to which the steel is heated controls the configuration of

the crystals, and consequently the forming properties of the final product. Metallurgists refer to three different stages in the annealing process: stress-relief, recrystallization, and grain growth.

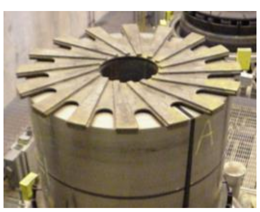
During stress-relief, the first stage reached at around 900 degrees Fahrenheit, the atoms move only small distances, pushed and pulled by surrounding atoms into a configuration in which the internal stresses are reduced but the boundaries between crystals remain unchanged. Halting the heat treatment after this stage retains most of the strength of the Full Hard product, but allows for greater formability. This strategy is called a stress-relief anneal or sunshine anneal, the latter a facetious suggestion that the relatively low temperatures might be achieved by setting the coil outside on a hot summer day.

Depending to some extent on the grade of steel and amount of cold-work performed on it, at around 1000 degrees Fahrenheit new crystals begin to form at the boundaries of the original, rolled grains. These crystals grow roughly into spheres, realigning atoms from the cold-worked grains until their boundaries meet up with those of other newly formed grains. Once the cold-worked grains have been consumed, the steel is fully recrystallized. At the completion of this phase the grains are very small, little more than a ten-thousandth of an inch across, and make for steel that is still stiffer than many applications call for.

After the steel has recrystallized, it continues to soften as the grains consume other newly formed crystals in the stage known as grain growth. The strategy for annealing the vast majority of CSI's cold-rolled sheet involves growing grains to a certain size: crystals that are in the neighborhood of a thousandth of an inch across provides the most popular combination of strength and formability. A common strategy for Drawing Quality steel involves manipulating impurities to allow the crystals to grow in only two directions, resulting in a coarse, 'pancake' grain structure that draws uniformly without stretching or tearing.

## BUILDING A CHARGE

Between three and seven coils up to 72" in outer diameter, and ideally with comparable dimensions, are stacked, on edge, on top of a base to form a charge. Each base provides the fan that will circulate the hydrogen 'gas stream', a sturdy foundation to support the 100+ tons of product and equipment, and the gas hook-ups, electrical connections, and sealing surfaces necessary for the different covers used during the annealing process. The coils are prepared for stacking first by threading an eye band through the middle to prevent the inside wraps from slipping loose, then orienting the coil 'eye-to-the-sky' using one of two upenders. Once the coils have been upended, overhead cranes lift them with powerful electro-magnets.



Between coils, spacer disks called convection plates are set to allow the gas stream to circulate along the coil side-walls and between the wraps. Balancing stack stability with heating efficiency considerations in designing the charge, coils and convection plates are alternately stacked up to a maximum height of just over twenty feet. Thermocouples are positioned to monitor the temperatures of the gas stream and base.

An inner cover made of stainless steel is lowered over the charge with an overhead crane, aligned by 9" diameter steel guide poles. Cooling water hoses are connected at the bottom to keep the seal from over-heating, and the cover is hydraulically clamped to the base. Nitrogen gas is forced into the sealed inner cover, purging the charge of air, and the assembly is tested for leaks. A furnace is then lowered over the inner cover, using the same guide poles, and natural gas, electrical power and electronic controls are connected.

## FIRING THE CHARGE

The furnaces combust natural gas mixed with air in up to eight burners to heat the inner cover from its outside. The burners will operate at maximum capacity for the first hour or so of the cycle to rapidly reach a furnace setpoint, typically around 1500 degrees Fahrenheit. The temperature of the gas stream is monitored, and as it approaches approximately 800 degrees inside of the inner cover, the burners cut back.

This gas stream temperature is held for 3 hours or so in what is known as a step, volatizing any rolling oils. The charge is allowed to soak at this temperature to bring the middle of the coils to the same temperature as the inner and outer laps before proceeding into temperatures that will begin to alter the steel metallurgically.

After the step, the burners will fire again to heat the gas stream further to around 1250 degrees. Pre-determined annealing parameters specify a temperature range within which the steel will achieve the desired properties. The cold spot and hot spot requirements are fed into a computer model that uses the thermal transfer properties of the charge to determine the gas stream temperature and soak time that will heat the deepest wraps sufficiently without over-heating the outer laps. The weight and geometry of the charge (outside diameter, width, and gauge, in order of importance) greatly affect the soak time that will be necessary to properly anneal the cold spot. Additionally, metallurgically critical products, like Physical Quality HSLA steels, for instance, will have tighter ranges and require longer soak times. Soak times vary from as short as 8 hours for small charges of Commercial Quality material to 24 hours or more. At the end of the soak, another leak test is performed on the hydrogen before exposing the inner cover to air.

## COOLING THE CHARGE

Controlled cooling of the inner cover and its contents is important both because the thermal shock of cold air can damage equipment and because the coils will cool, and contract, beginning with the outer wraps. The steel is hot enough and clean enough that this latter effect can result in pressure in the contracting coil that is sufficient for the crystals to grow across wraps, effectively welding the coil together. When the steel is payed off onto the Temper Mill, the wraps stick together and the steel is strained as they pull apart. To reduce the occurrence of 'stickers', some products are furnace-cooled for an hour or more.

The furnace is replaced with a cooler, which has two fans mounted in the top to circulate cold air around the inner cover. A few hours into the cooling cycle, when the inner cover has cooled to around 600 degrees, water sprays in the cooler expedite the process. A few hours after that, when the charge has cooled to around 200 degrees, the cooler is removed, the hydrogen is purged with nitrogen, the inner cover is removed, and operators break the charge. The coils are staged between annealing and the Temper Mill, where they will continue to cool for another couple of days. The steel at this point is susceptible to rust, so they are promptly scheduled for temper rolling. Overall, heating and then cooling charges requires a few days.

## TEMPER MILL

After annealing, the steel has been so thoroughly relieved of internal stresses that it has a tendency not to bend uniformly, resulting in localized strains (similar in appearance to stretch marks in human skin) during subsequent forming operations.

To counter this, a light reduction, between ½ and 3½ percent of the thickness, is taken at the Temper Mill. Similar in some ways to the 5-stand, the Temper Mill is made up of two '4-Hi' rolling mill 'stands' arranged in series. The tandem arrangement gives operators the flexibility to improve the flatness of the product and to allow a 'matte' surface finish to be applied by the shot-blasted work-rolls while meeting the targeted reduction, or 'extension'. Work rolls are changed each day or so, after which the widest scheduled coils are processed. As at the 5-stand, coils are rolled from wide-to-narrow in a 'come-down'.

Unlike the 5-Stand, power is delivered from the four mill motors to the back-up rolls, which turn the work rolls, which in turn roll the steel. The reductions are much smaller, so less tension is held between stands and the roll coolant / solution system is not normally used. Operators at the temper mill are relied upon to make most adjustments based on the rolling parameters and product appearance.

Oil can be electro-statically applied either 'lite' or 'heavy' by coating the top surface of the coil as it is wound onto the tension reel. If necessary to make the customer's coil weight requirements, coils can be split with a shear at the exit of the last stand. At the exit side of the second mill, a gamma-ray thickness measurement device uses radioactive material to record the gauge of the steel. Footage counters at both the entry and exit ends consist of rubber-coated wheels that are turned by the strip; each revolution is counted and translated into a length measurement. These instruments record the coil footage for TMW billing, as well as the extension achieved during temper rolling.

## PREPARATION AND THREADING

Coils are staged for temper rolling on a flat-top conveyor, which positions the annealed coils at the downender. Once the coils are returned to eye-horizontal, conveyor equipment positions the coil at the front of the temper mill, and the stub mandrels, one on each side, close into the eye of the coil.

Large electro-mechanical screws allow for adjustment of the gap between work rolls. An operator monitors the steel exiting each mill, steering the head-end by operating one of the screws. After the head-end is under-wound onto the tension reel, and tension has been established through the mills, the operator makes further adjustments to the roll gaps, tension settings, and work-roll bending (up to 110 tons of either crown-in or crown-out, as at the 5-stand). Initially, steel is slowly rolled while final adjustments are made; when the operator is satisfied, the mills accelerate to their run speed - up to 3600 feet per minute (40 mph) - at which further adjustments are not normally made.

## TAIL-OUT AND INSPECTION

When the coil has payed off down to the last few wraps, it is sheared and the inner-most, off-gauge wraps are removed from the stub mandrels with a small jib crane and scrapped. At the exit end, the finished coil is manually banded by an operator with a single, circumferential, belly band, and, if the coil is ready for bundling, with one eye band as well. More bands can be added as desired by the customer.

A short sample is sheared from the tail of the coil at the exit end and examined to assess the quality of the coil's surface, confirm the dimensions, and evaluate the effectiveness of the anneal and temper. Where indicated on the schedule, the surface texture of the sample is evaluated to ensure the customer will be able to paint, or otherwise process, the steel efficiently. The metallurgical properties of the steel are evaluated either by cutting coupons for tensile testing at the Physical Test Lab to qualify Physical Quality material for shipment, or by examining the Rockwell Hardness of the steel. This latter test is done at the temper mill with a machine that makes a tiny impression in the product's surface with a hardened steel ball. The size of the impression after the test is an indication of the degree to which the steel will resist being formed into a finished product by CSI's customers.

Coils are packaged at the Cold Sheet Mill to protect the steel: high-quality paper is wrapped around the coil and a sleeve inserted into the eye to keep moisture out, and protectors placed on the corners reduce transportation damage. Product is staged in the nearby shipping bay for loading onto either truck or rail car.