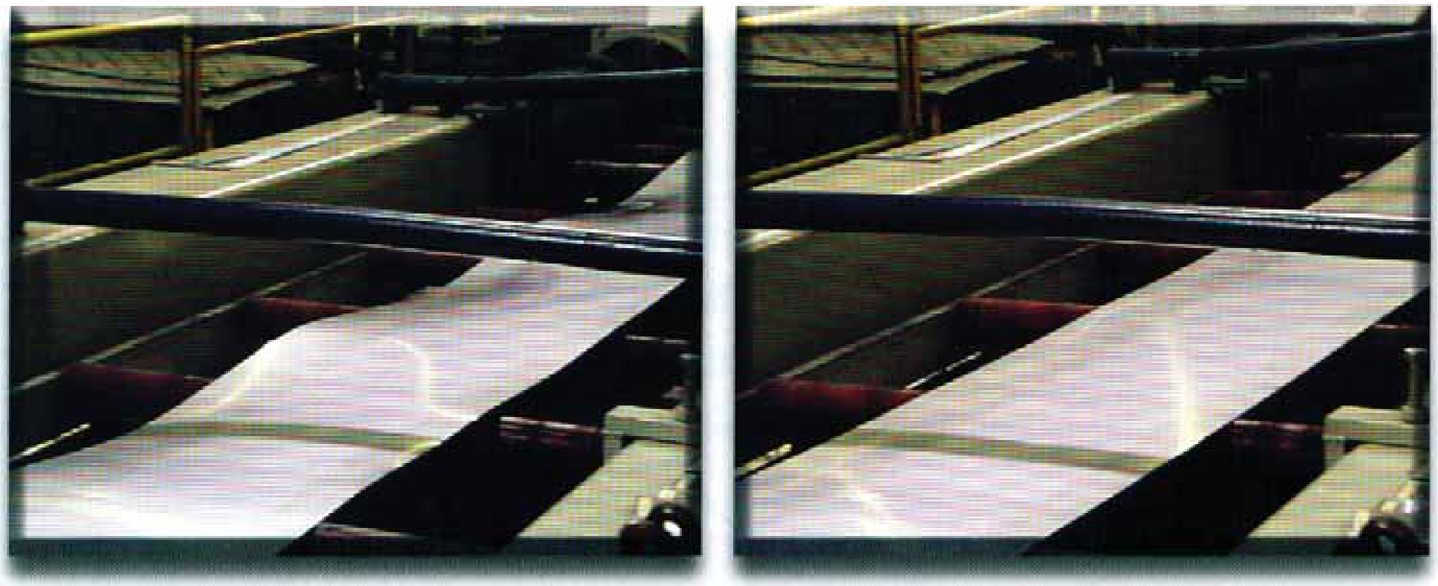
Official Publication of the Fabricators & Manufacturers Association, Intl.® www.fmanet.org November 2004 Vol. 34 No. 11
Visit *The FABRICATOR*'s Web Site at www.thefabricator.com

the fabricator®
Your main source of industry news



HOW FLAT IS THAT?

Achieving coil shape correction and quantifying its flatness

By Michael Kelly

Today's sophisticated fabricated metal parts require ever more stringent flatness tolerances. Laser cutting, high-speed blanking, and progressive stamping require camber-free, flat product as its feedstock. These highly automated fabrication techniques can get bogged down by a factor that seems elementary: poor feedstock shape. However, achieving good feedstock flatness is easier said than done.

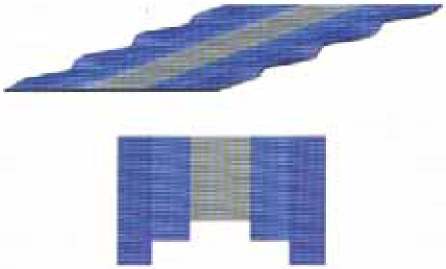


Figure 1
Edge wave occurs when a strip's edges (dark blue sections) are longer than its center (gray section).

Rolling a coil of metal is a complicated process. Several variables must be controlled on a dynamic basis to roll a good shape. Mills have spent large sums of money on systems dedicated to controlling their products' shapes. However, many of the rolling practices occur at very high tensions, and it can be difficult to recognize shape problems at these high tensions.

Typical shape problems include edge wave, center buckle, quarter buckle, camber, crossbow, oil can, and twist. A coil develops a shape defect (or defects) when one section is rolled longer than an adjacent section. For example, edge wave occurs when a strip's edges are slightly longer than the strip's center. To illustrate this length difference, imagine that a coil is slit into narrow strips. The strips near the edges are longer than the strips near the center of the coil (see **Figure 1**).

Other shape defects can arise in downstream processes such as annealing, slit-

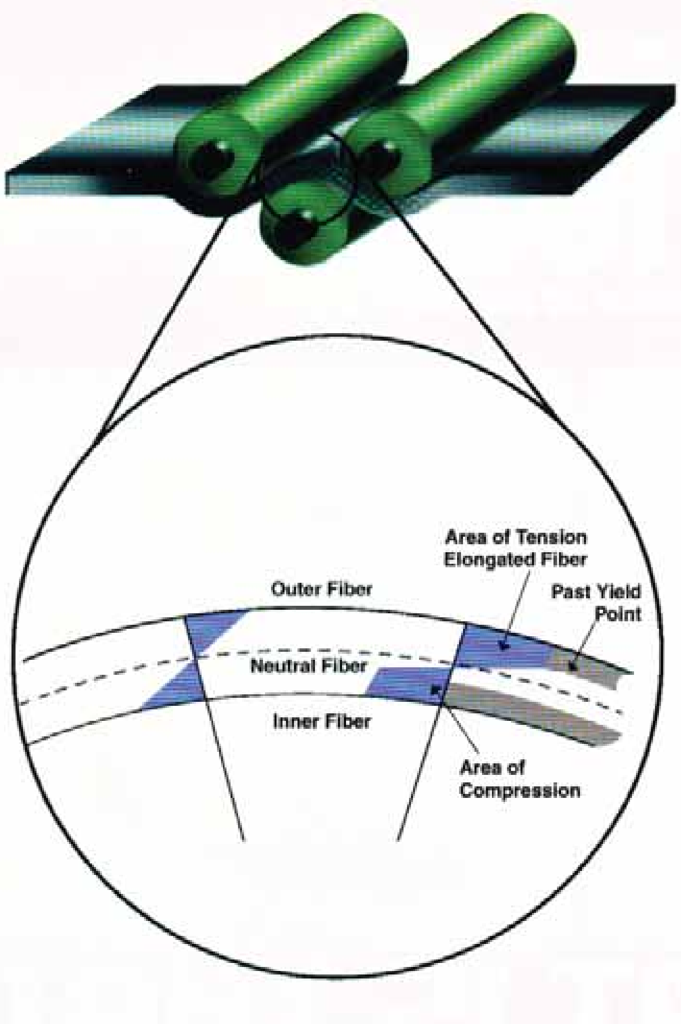


Figure 2

Rolls cause outer fibers to stretch (in tension) and inner fibers to compress (in compression). Fibers on the neutral axis are in neither compression nor tension. A band of material near the neutral axis is unchanged because the bending near the neutral axis is not sufficient to plastically deform the metal.

ting, and cutting to length. In each case a shape problem can be traced back to length differentials in adjacent portions or residual stresses remaining in the metal.

Before fabrication processes became highly automated, shape correction often was performed on a sheet-by-sheet basis. The materials were placed in a sheet stretcher, clamps were closed at both ends, and the sheet was elongated linearly by the use of hydraulic cylinders that moved one of the clamping heads. The current ASTM A480M stretcher-leveled specification for hot-rolled and cold-rolled sheets refers to this standard. Properly performed, sheet stretching produces as flat a product as possible. This process is still the benchmark for flatness.

Talk abounds about shape correction methods that "relieve" residual stresses. This is not accurate manufacturing jargon—stress-relieving cannot be accomplished by mechanical means. Stresses in metal coil are relieved by thermal processes such as annealing. When a mechanical method is used, the process is called *shape correction*, not stress-relieving. Shape correction is a complex process that requires an understanding of types of stresses that are applied to strip, how they are applied, whether the stresses are equalized, and whether the shape correction is permanent.

Three methods for shape correction are roller leveling, tension leveling, and stretcher leveling.

Roller Leveling

To remove defects permanently from metal strip, the strip must be elongated past its yield point. This means that the coil has to be stretched past its elastic stage (the stage at which the metal retains its shape characteristics, including defects) and reach its plastic stage (or yield point). During roller leveling, the outside surface of the metal (that is, the surface farthest from the bending roll) is in tension and is stretched. If the amount of bending is sufficient, a region near the outside surface will elongate enough to deform plastically (see **Figure 2**). The surface of the strip nearest to the bending roll is in compression. The material along the center of the strip is in neither tension nor compression—it is neutral and is called the *neutral axis*. On the subsequent reverse bend, the opposite surfaces are in compression and tension. However, a band of unyielded material, that along the neutral axis, has not been compressed or stretched. Only the top and bottom surfaces of the metal have been plastically deformed, or stretched past the metal's yield point. The center of the strip remains elastic or unchanged. No permanent correction has occurred (see **Figure 3**).

When a coil exhibits edge wave (see Figure 1), the operator of the leveler engages backup wedges on the bending rolls. The section of the strip with the shorter fibers gets more bending when the backup wedge is applied. The shorter fibers are elongated to a greater extent than the longer fibers. When the strip exits the leveler, the material is flat. The leveler has created a sandwich in which the top and bottom sections have been plastically deformed, and the center band is still unchanged.

The metal is flat because the stressed skin contains all the uneven stresses in the metal. If the sandwich is disrupted at the next process, shape problems can arise. For critical-flatness applications such as laser cutting, the shape that has

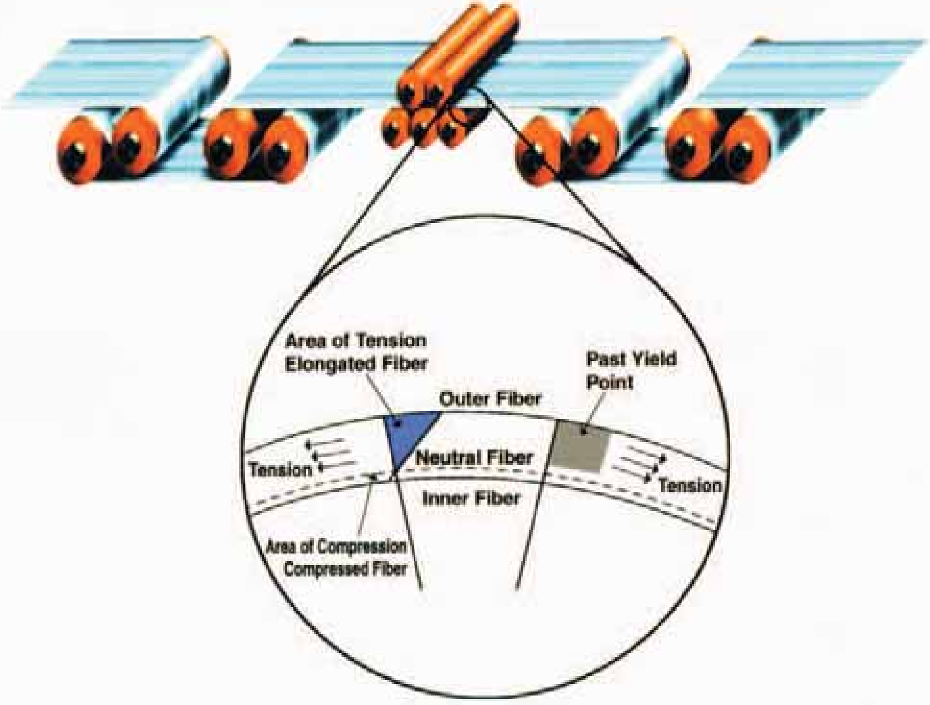


Figure 5

Tension causes the neutral axis to move toward the bending roll. On the next pass the axes switch sides, and the neutral axis moves toward the top of the strip. This puts the entire thickness under enough strain to facilitate a true shape correction.

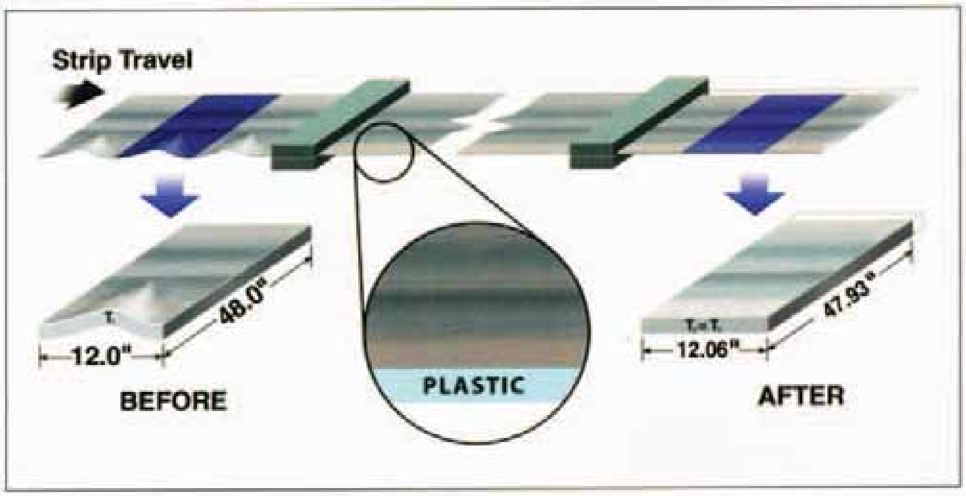


Figure 6

Stretcher leveling stretches one section of a coil at a time, and it puts the entire thickness into plastic deformation.

correction begins only after the required amount of bridle speed differential is achieved, the amount of uncorrected coil can be significantly more than the distance from uncoiler to recoiler. It is common that several of the beginning and finishing wraps still have shape issues. In addition, coil set, which is caused by the bend over the last roll while under tension, can affect some portion of the coil.

The gauge range is a function of the material, the bending roll size, and the system horsepower. Similar to roller leveling, tension leveling has a finite thickness range for a given material. The machine also is limited to one or two types of metal for a given design, in part because of the different cleaning requirements and in part due to the different mechanical properties of the metals. For cold-rolled steel, this range may be 0.008 to 0.100 in. thick.

Tension leveling devices can operate at high speeds and can be very productive, especially when run continuously on the materials for which it is best-suited. However, the process has some drawbacks. Highly polished or painted products can exhibit friction digs. If the process must be stopped in the middle of a coil under tension, the section under the bending rolls will exhibit a significant leveler stop. Last, the process is limited in the maximum shape correction it can accomplish, which depends on the size of the bending rolls, the horsepower, and the maximum bridle roll speed differential.

Stretcher Leveling

The linear stretching method has been used for decades to stretch sheet and plate. A modern approach to this technology allows it to be used in a coil-to-coil format. Using a stop-start process, metal is uncoiled, gripped in a nonmarking system, and stretched beyond its yield strength to correct waves, buckles, and camber permanently. As the corrected increment is recoiled, a new, unstretched increment is introduced into the machine (see **Figure 6**).

The process uses no leveling rolls and does not require cleaning. The short fibers shown in Figure 1 are elongated to match up with the longest fibers. The shape correction is permanent, and the stresses remaining in the strip are equalized throughout the cross section.

Like tension leveling but unlike roller leveling, stretcher leveling causes the width to decrease.

Coil-to-coil stretching is a stop-start operation, so it is inherently slower than tension leveling and compares to the speed of roller leveling. However, the start-stop nature of the operation allows flatness measurements to be made roubeen trapped by the top and bottom skin can spring back after the yielded skins are disrupted because the internal stresses were not equalized.

The litmus test for shape correction permanence is accomplished by measuring the material's width change. The width does not change in roller leveling because the leveler does not permanently yield the entire cross section of the strip (see Figure 3).

The gauge range for roller leveling depends on the thickness of the material and on its yield strength. Because elongation is accomplished by bending the material over a roll, the diameter of the work roll determines the minimum gauge. The maximum thickness is determined by the deflection in the machine and the horsepower required. The device also has to be designed for the type of material because the stress-strain curves are different for every type of metal. Therefore, a given leveler has a gauge range limitation for a given material. Typically, a roller leveler is used to process one or two types of metal. For a work roll 1.75 inches in diameter, the effective gauge range for cold-rolled steel is 0.030 in. to 0.135 in.

Roller levelers operate at moderate speeds and result in no yield loss, and although the process is suitable for many leveling applications, it does have some limitations and restrictions. For instance, roller leveling is limited in the amount of shape correction it provides. If an edge wave is too large, a roller leveler might not provide a sufficient degree of roll bending, or elongation, to eliminate the defect completely. Roller levelers cannot change camber in a strip. If the material is stopped during the leveling process, the rolls are likely to leave an impression in the strip.

Because the rolls contact the material's entire surface, they have the potential to damage it; all of the work rolls, intermediates rolls, and backup rolls must be free from debris to reduce the likelihood of causing surface defects.

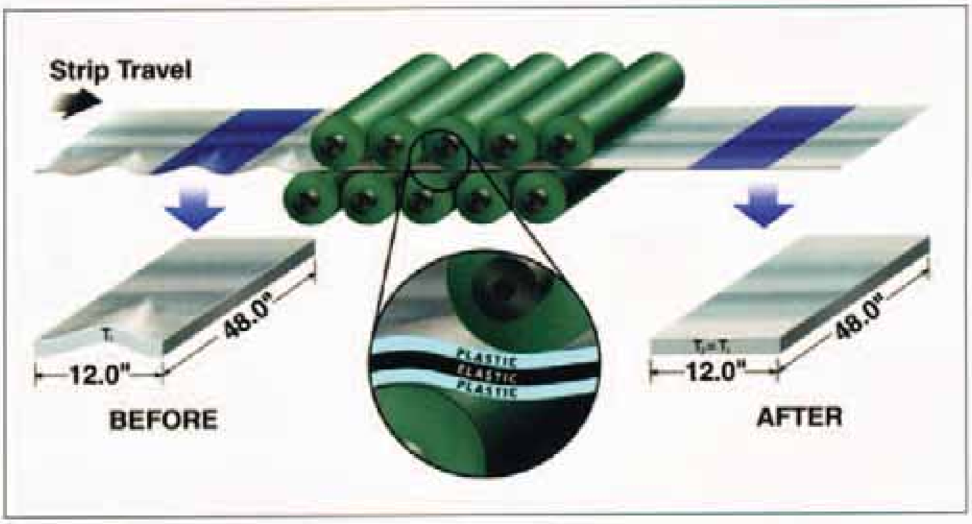


Figure 3

Although roller leveling causes fibers along the top and bottom of the strip to deform plastically, the center section does not get to a plastic state—it remains in its elastic state.

Figure 4

Like roller leveling, tension leveling uses bending rolls (center) to change the coil's shape. It also uses bridle rolls (left and right) to apply tension to the strip.

Tension Leveling

Tension levelers also correct shape by bending the metal over rolls. However, in tension leveling, the shape correction process is performed under tension. The process is usually performed while the material is in coil form. Tension leveling equipment typically has several bridle rolls before and after the bending roll unit (see **Figure 4**). Also, a cleaning section often is incorporated so the material does not slip on the bridle rolls.

The tension is accomplished by establishing a speed differential between the entry and exit bridles. The exit bridle speed is up to 1.5 percent faster than the entry bridle. When the metal is bent over a roll, the tension moves the neutral axis of the strip closer to the bending roll. More than half of the top cross section of the strip is elongated past the yield point (see **Figure 5**). On the next bend the remaining unyielded material on the bottom is plastically deformed. Unlike roller leveling, the entire cross section of a tension-leveled product is plastically deformed, which causes width reduction.

Most tension leveling is performed coil-to-coil, and therefore it can be a high-speed process. Although most of the coil gets permanent shape correction, tension leveling does not correct the shape of the entire coil, for two reasons. First, the coil must be in the reels to achieve the tensions required for the permanent correction. Second, because the bridles add the incremental tension required to move the neutral axis, the machine has to achieve the correct speed differential between the entry and exit bridles. This takes time.

The amount of coil that does not get permanent shape correction is, at minimum, the distance from the uncoiler to the recoiler. Because permanent shape

> **The linear stretching method has been used for decades to stretch sheet and plate. A modern approach to this technology allows it to be used in a coil-to-coil format.**

tinely throughout the coil without a series of leveler stops that may damage the material. Because the process uses no bending rolls, it minimizes the opportunity for scratching or rolling defects. The nonmarking grippers touch less than 1 percent of the surface of the strip, which limits their potential for damaging the material's surface.

A stretcher leveling system can process thicknesses from 0.006 in. to 0.250 in. in steel, aluminum, stainless, nickel and cobalt alloys, and titanium and with finishes that include hot-rolled, cold-rolled, bright annealed, polished, buffed, painted, embossed, anodized, and tempered.

The process is essentially unlimited in the severity of shape defects it can correct. It can handle edge wave in excess of 10 in. in height and it can eliminate camber.

Quantifying Flatness

Assigning benchmark criteria for defining flatness in coiled metal can be confusing. ASTM and ANSI standards describe tolerances relating to the maximum wave height in 8 ft. of coil, but make no mention of the number of waves. A shape defect—for example, a ½-in. edge wave—that repeats every 6 in. is much more severe than the same defect repeating every 36 in.

The aluminum industry uses I-units for measuring flatness. The method assumes a sinusoidal edge wave (the wave has a given height over a given distance). Because it requires interval measurements, the I-unit approach defines flatness much more quantitatively than commercial standard specifications do.

The formula for calculating an I-unit is:

$I = (H \times \pi/2L)^2 \times 10_5$

Where:

H = edge wave height

L = distance between edge waves (crest-to-crest or trough-to-trough)

The formula can be simplified to

$I = (H/L)^2 \times 246{,}740$

Using the first coil in the example (the coil has ½ in. of edge wave that occurs every 6 in.),

$I = (0.5/6)^2 \times 246{,}740$

I = 1,713 units

Using the second coil in the example (the coil has ½ in. of edge wave that occurs every 36 in.),

$I = (0.5/36)^2 \times 246{,}740$

I = 48 units

A fabricator must consider two factors to achieve proper feedstock flatness. One is to select the technique that is most suitable for the material, and the other is to choose the method that can most economically achieve the required flatness as measured in I units.

Michael Kelly is a metallurgical engineer with Leveltek Processing LLC, 748 McMechen St., Benwood, WV 26031, 304-232-8530, fax 304-232-8536, mike@leveltek.com, www.leveltek.com.

Reprinted with permission from THE FABRICATOR, November 2004. © The Croydon Group, Ltd. All Rights Reserved. Visit our website at www.thefabricator.com *FosteReprints: 866-879-9144*

Leveltek

Leveltek Processing
748 McMechen Street • P.O. Box 10
Benwood, WV 26031

Mike Kelly, President
mike@leveltek.com
Glenn Wilson, VP Sales & Marketing
glenn@leveltek.com

(304) 232-8530 • (304) 232-8536 fax
www.leveltek.com