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.

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-
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.

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 rou-
been 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.

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**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.

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**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 briddles. The exit briddle speed is up to 1.5 percent faster than the entry briddle. 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 briddles add the incremental tension required to move the neutral axis, the machine has to achieve the correct speed differential between the entry and exit briddles. 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
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tinley 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:

\[ I = (\frac{H \times \pi}{2L})^2 \times 10^3 \]

Where:

- \( H \) = edge wave height
- \( L \) = distance between edge waves (crest-to-crest or trough-to-trough)

The formula can be simplified to

\[ I = (\frac{H}{L})^2 \times 246,740 \]

Using the first coil in the example (the coil has \( \frac{1}{6} \) in. of wave edge that occurs every 6 in.),

\[ I = (\frac{0.5}{6})^2 \times 246,740 \]

\[ I = 1,713 \text{ units} \]

Using the second coil in the example (the coil has \( \frac{1}{36} \) in. of edge wave that occurs every 36 in.),

\[ I = (\frac{0.5}{36})^2 \times 246,740 \]

\[ I = 48 \text{ units} \]

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.
