Hot-Dip Galvanized Sheet Production Course

January 26-28, 2021

Virtual Seminar

Sponsored by:

International Zinc Association, GalvInfo Center

After Pot Processes

After Pot Processes

- Strip Cooling
- Temper rolling
- Leveling
- Discontinuous yielding
- Coil winding
- Ridges and build-up

Strip Cooling

After Pot Cooling

- Vertical Plenum
- 200 HP variable speed drive
  Capacity 8800 CFM
- Maintains strip temperature at 345°C at the head roll

ArcelorMittal Dofasco
Hamilton, ON

Strip Cooling

After Pot Cooling Quench Tank

- Strip exit temperature 38°C max
- One set ringer rolls 300 x 1525 mm
  - Hypalon covering
  - Hardness 55-65 durometer
- Recirculated water cooling

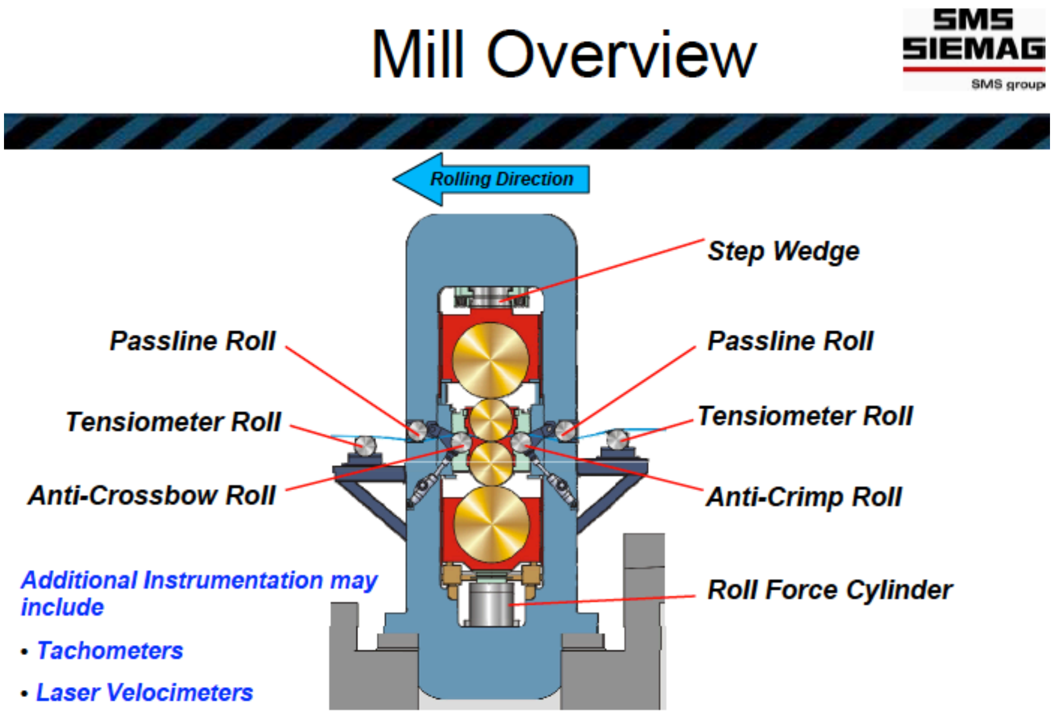
ArcelorMittal Dofasco
Hamilton, ON

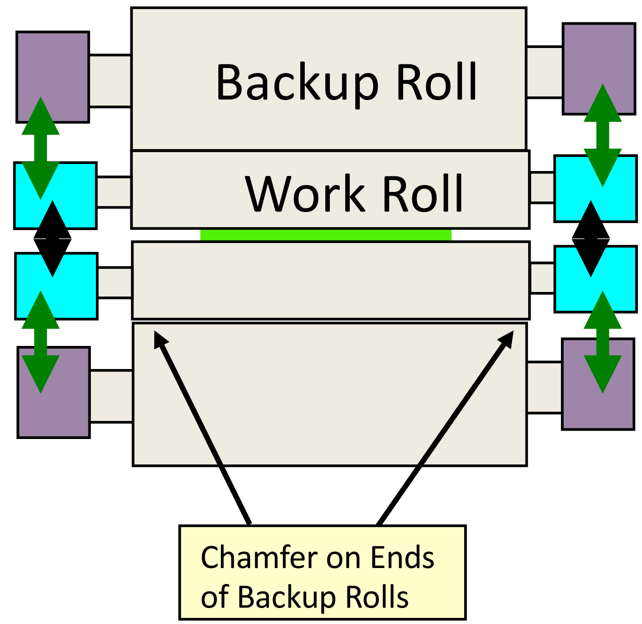
Temper Rolling & Tension Leveling

Introduction

- Temper rolling in modern galvanizing lines typically involves a single light pass by an in-line 4-High Mill. Reduction is typically between 0.5 and 1.5 % - and is **not** to reduce or control thickness but rather to ....
  - **Eliminate discontinuous elongation/yielding**
  - **Condition the strip surface (imprint roll surface texture)**
  - **Improve strip shape/flatness**
  - **In practice, the last of these objectives is the most difficult to achieve**
- Operation is still (surprisingly) manual – closed loop shape control is uncommon – probably due to cost and process modeling problems
- Tension levelers are a less expensive and require much less operator attention than temper mills. They achieve shape/flatness and discontinuous elongation objectives, but cannot alter surface texture

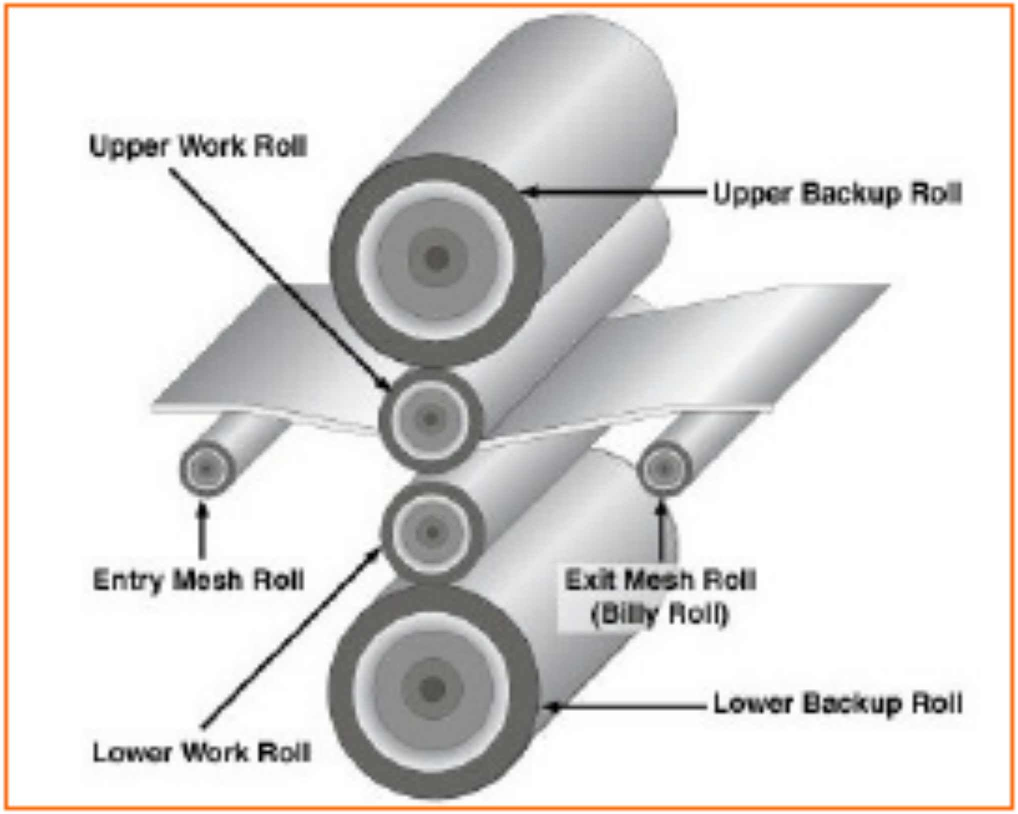
Temper Rolling





4-High Mills employ work roll bending to change loaded profile independently of mill load

Temper Rolling



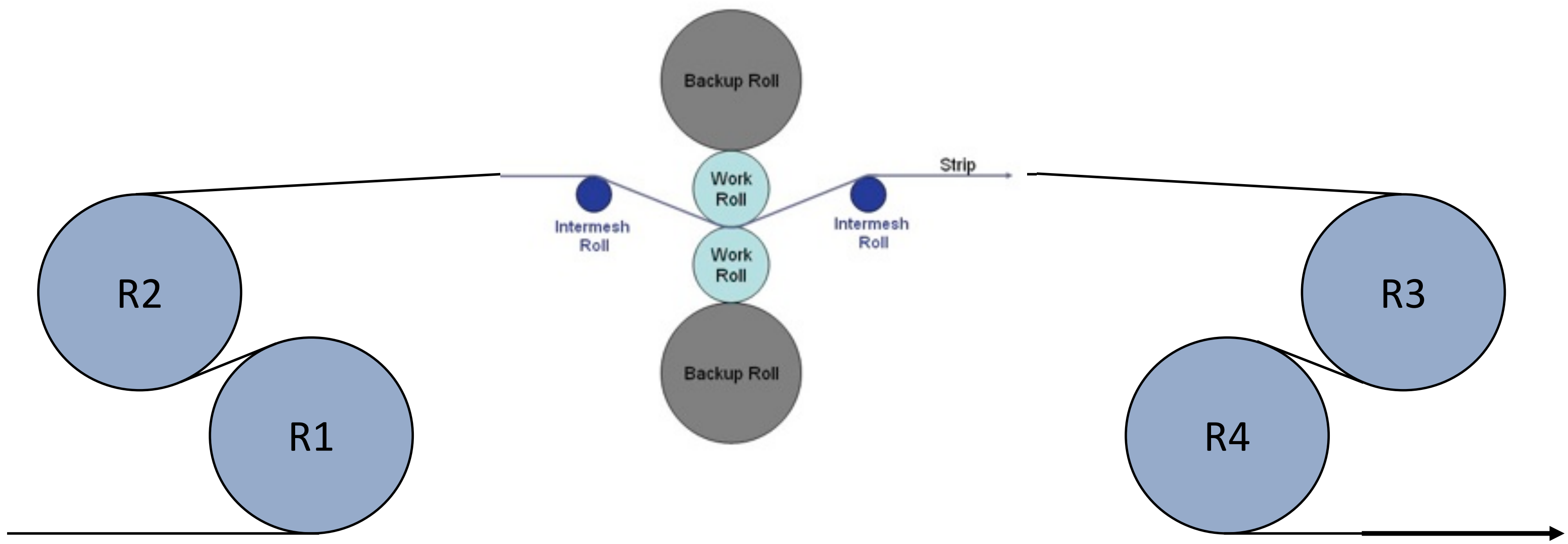
Most modern temper mills have a 4-High design – with entry and exit mesh rolls to control the angle at which the strip enters and leaves the roll bite. (This stabilizes the rolling process – reducing crimps and related defects.)

The 4-High configuration utilizes work roll bending – which involves powerful hydraulic rams acting on the work roll chocks.

This allows strip shape to be controlled (within limits) independently of rolling load/elongation.

Temper Rolling

Temper rolling, and tension leveling, are facilitated by high tensions that are isolated from the rest of the line by powerful bridles.



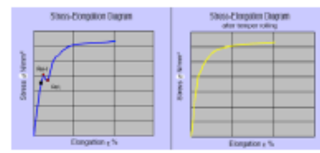
Speeds and rolling force are very low cf. cold rolling. On line work roll cleaning is frequently employed. Work roll life is thousands of tons. Temper rolling may be dry or “wet” – utilizing a (usually) non recirculating water based temper fluid. Requires a system for fast work roll change without cutting the strip/stopping the line.

Effects of Temper Rolling

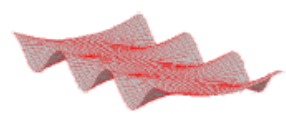
Objectives

SMS SIEMAG
SMS group

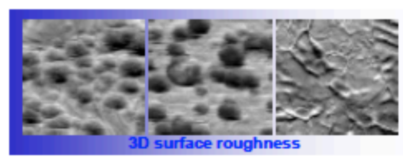
- *Suppress YPE elongation / modify properties*



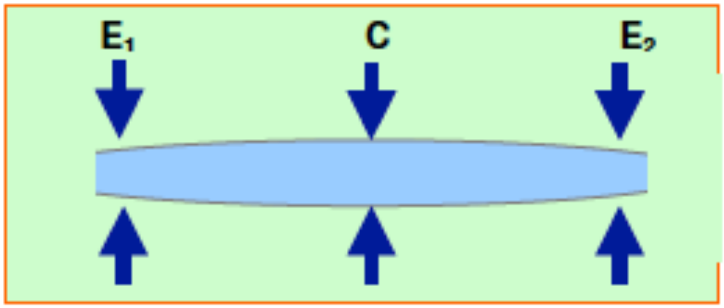
- *Improve flatness*



- *Modify strip surface*



Flatness versus Profile

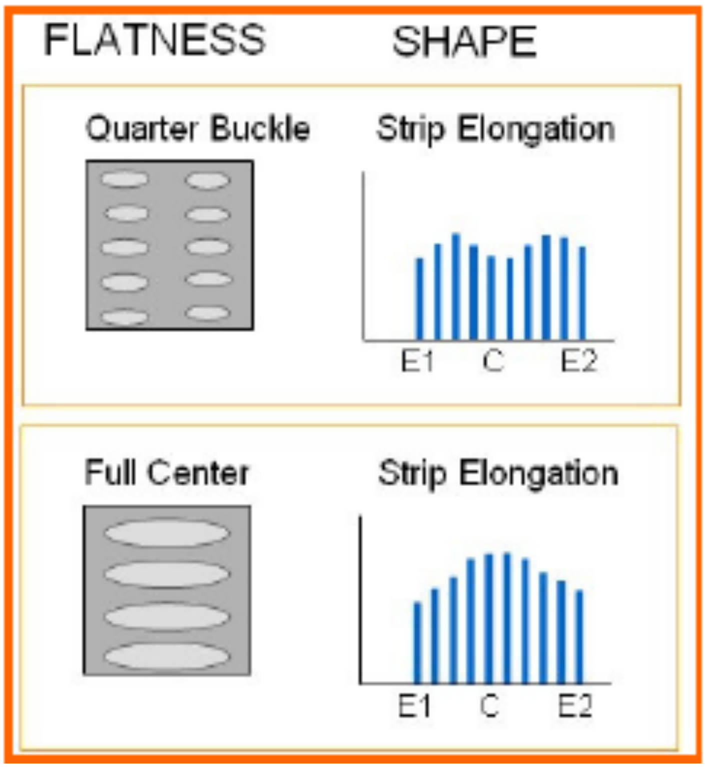


$$\text{Crown} = C - \left(\frac{(E_1+E_2)}{2}\right)$$

$$\%\ \text{Crown} = 100\ (\text{Crown} / \text{Av Thickness})$$

- “Profile” refers to thickness variation across the width of a strip, i.e., in the transverse direction – it has two components – termed “crown” and “edge drop”.
  - Crown is the thickness change from the center of the strip to a location 25 mm from each edge
  - Edge drop is the thickness change which occurs between the very edge of the strip and a location 25 mm from the edge

Improving Flatness by Temper Rolling



Most temper rolled strip goes either to paint lines, or directly to automotive or appliance customers

Strip flatness – meaning absence of buckles & waves – is critical in these applications

Effects of Temper Rolling

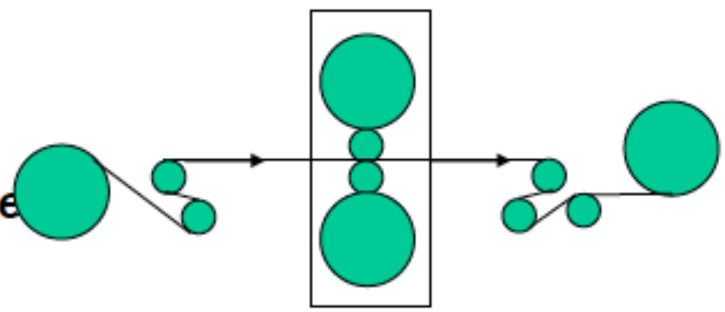
Surface texturing

ArcelorMittal

Why ?

To apply the right roughness for:

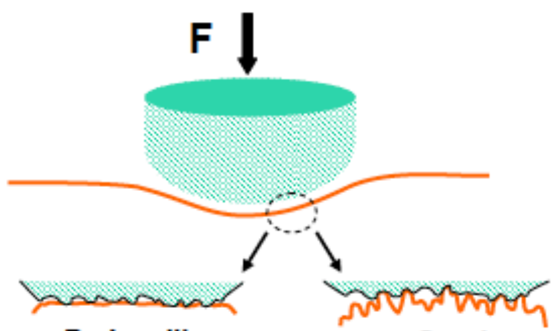
- ***enhanced oil retention***
- ***better formability of the steel***
- ***improved painted finish***

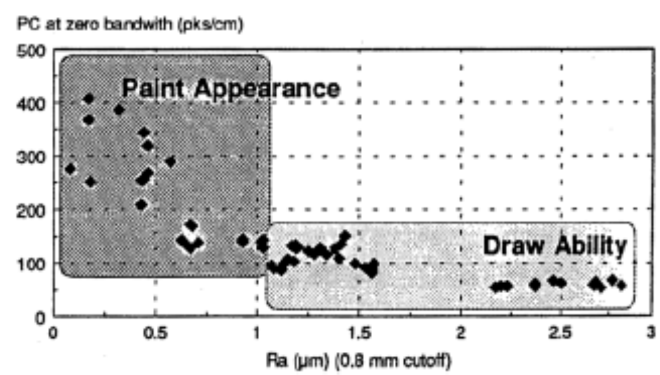


Effects of Temper Rolling

Surface texturing

Sheet texturing: a compromise





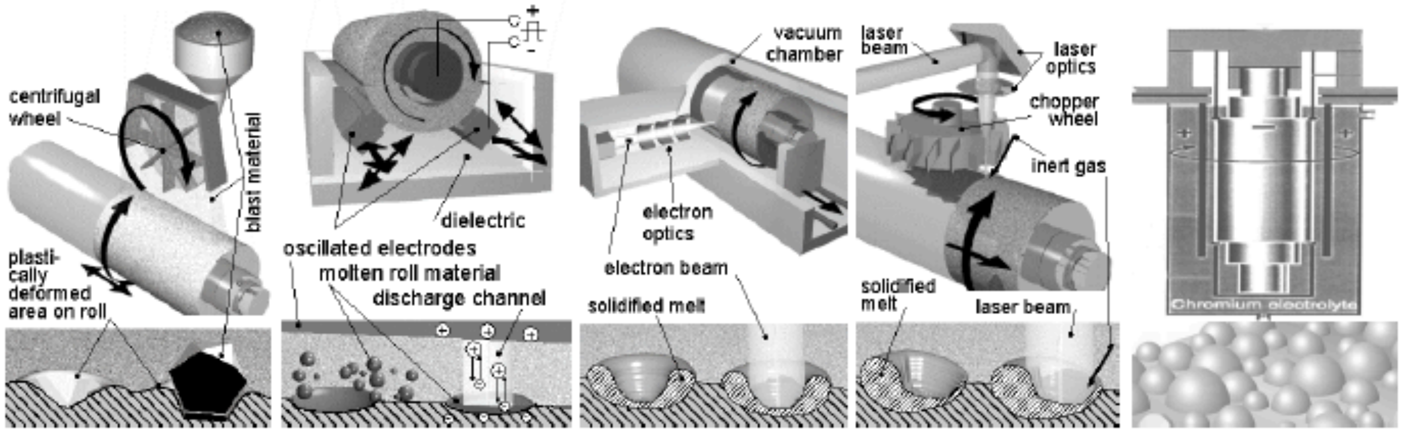
Enough roughness to trap lubricant and avoid metal-to-metal contact during forming

Not too high Ra and low Wca to restrict the “orange peel” appearance

Work Roll Surfaces

Roll texturing

Roll texturing technologies:

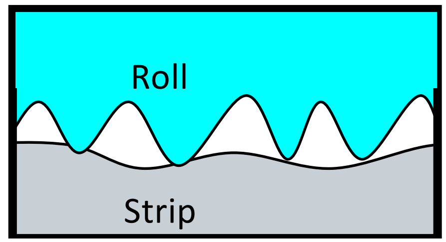


Grit Blasting | **Electric Discharge Texturing** | **Electron Beam Texturing** | **Laser Texturing** | **Topocrom**

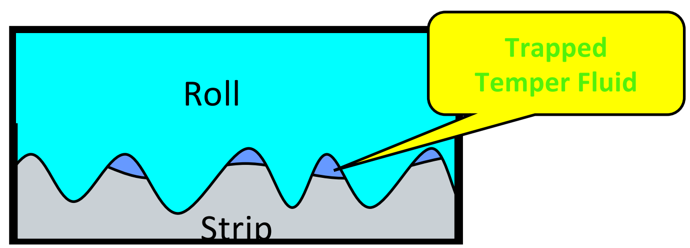
Temper Rolling

Work roll texture transfer – increases with mill load

Asperities on the roll first penetrate into the strip.....



At a later stage, the mechanism becomes one of reverse extrusion and the curve flattens...



In the case of wet temper rolling, entrapment of incompressible fluid reduces roll texture transfer

Temper Rolling

Effects of Temper Rolling on Galvanized Sheet Surfaces

- Because zinc is so soft, temper rolling effectively flattens (flows) high spots/bands associated with various coating imperfections. Painted appearance improves accordingly
- Eliminates spangles, spangle boundaries other features which could otherwise show through paint films, when the spangles are small
- Temper rolling does not smooth large spangles
- Provides locations for the entrapment of forming lubricants
- Leaves the surface in a much more active (reactive) condition – probably associated with the breaking of oxide films, increasing of surface area and structural deformation
  - Reaction with passivation and paint line pre-treatment chemicals increases correspondingly

Tension Leveling

Temper rolling mills are expensive to operate and require much operator expertise and attention - but they are the only way to achieve surface conditioning.

When skin passing is not required, tension levelers are a cheaper and better way to improve shape and remove discontinuous elongation. They do not condition strip surface – but this is not required for most commercial product.

Strip shape could theoretically be improved just by using two very powerful bridles to pull it until it extended.

In practice however, required tension is reduced and control is improved by simultaneously bending the strip over small diameter intermeshing rolls.

Tension Leveling

Why Tension Level?

- Tension leveling is applied to correct shape defects.
  - buckles, waves, and limited camber correction
- Tension leveling suppresses Yield Point Elongation.

Tension Leveling

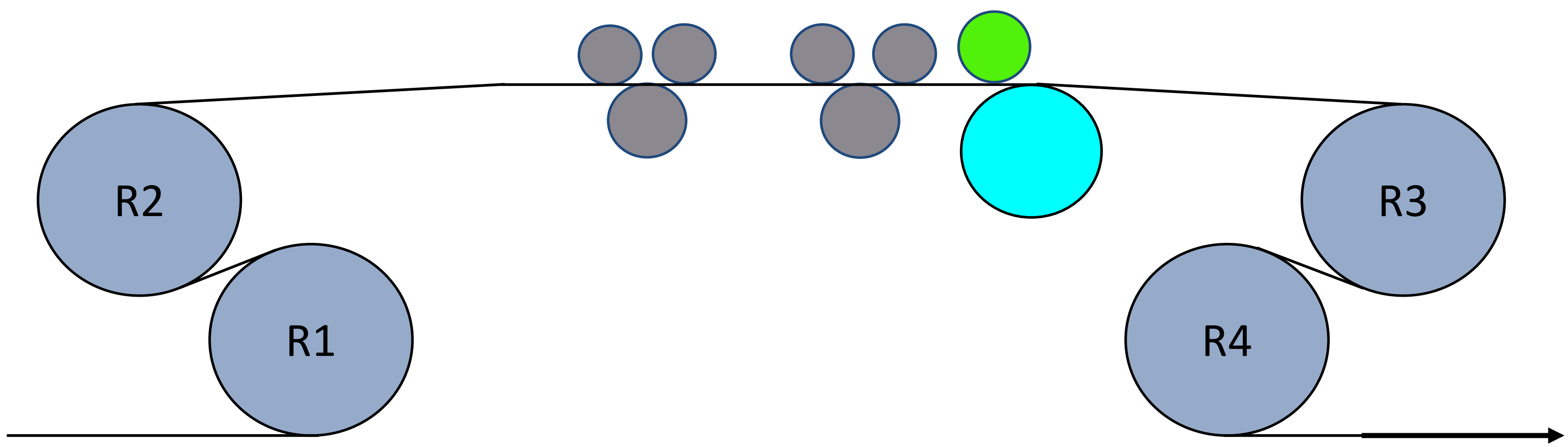
What is Tension Leveling?

– **Tension leveling** is permanently elongating strip by passing it over a few small diameter rolls under tension.

– Comparisions:
  - **Stretch leveling** elongates the strip under very high tension without bending rolls.
  - **Roller leveling** locally compresses & elongates strip without significant tension.

Tension Leveling

Within the leveler there are usually two independent bending roll sets – each of which contains an upper and lower bending roll cartridge. (A larger anti cross bow roll is frequently installed downstream). Tension is very important in in this process and is provided by bridles in front of and behind the leveler unit.

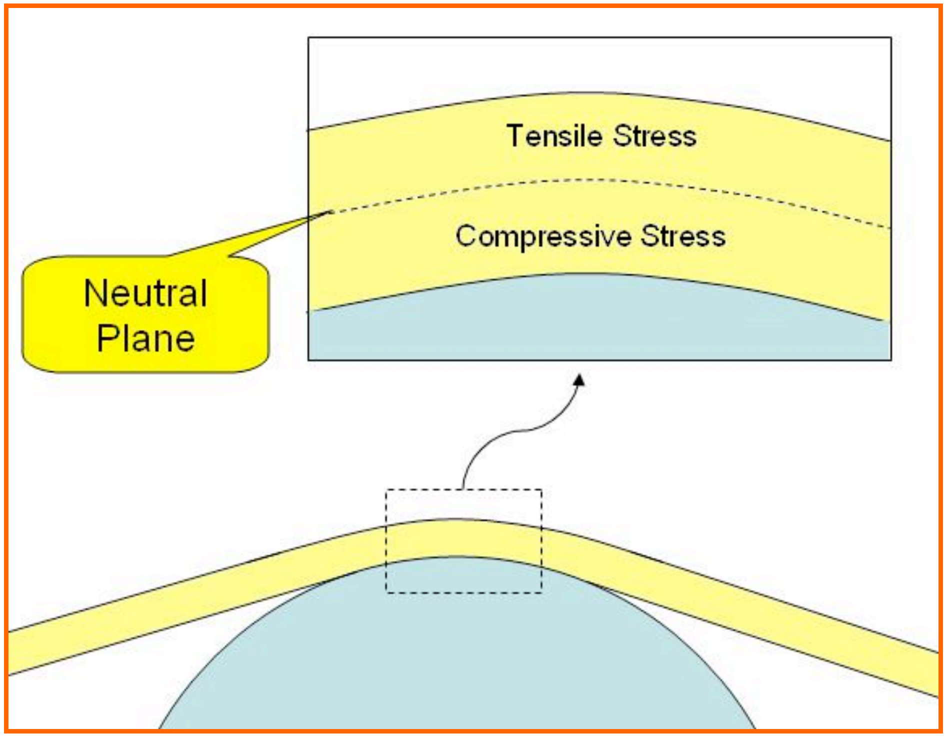


The pulse generator on R3 usually provides the speed master for the unit, with an additional pulse generator on R2 being used to calculate overall elongation through the bending roll unit. (Alternate designs utilize a cross shaft between bridles to control elongation.)

Tension Leveling

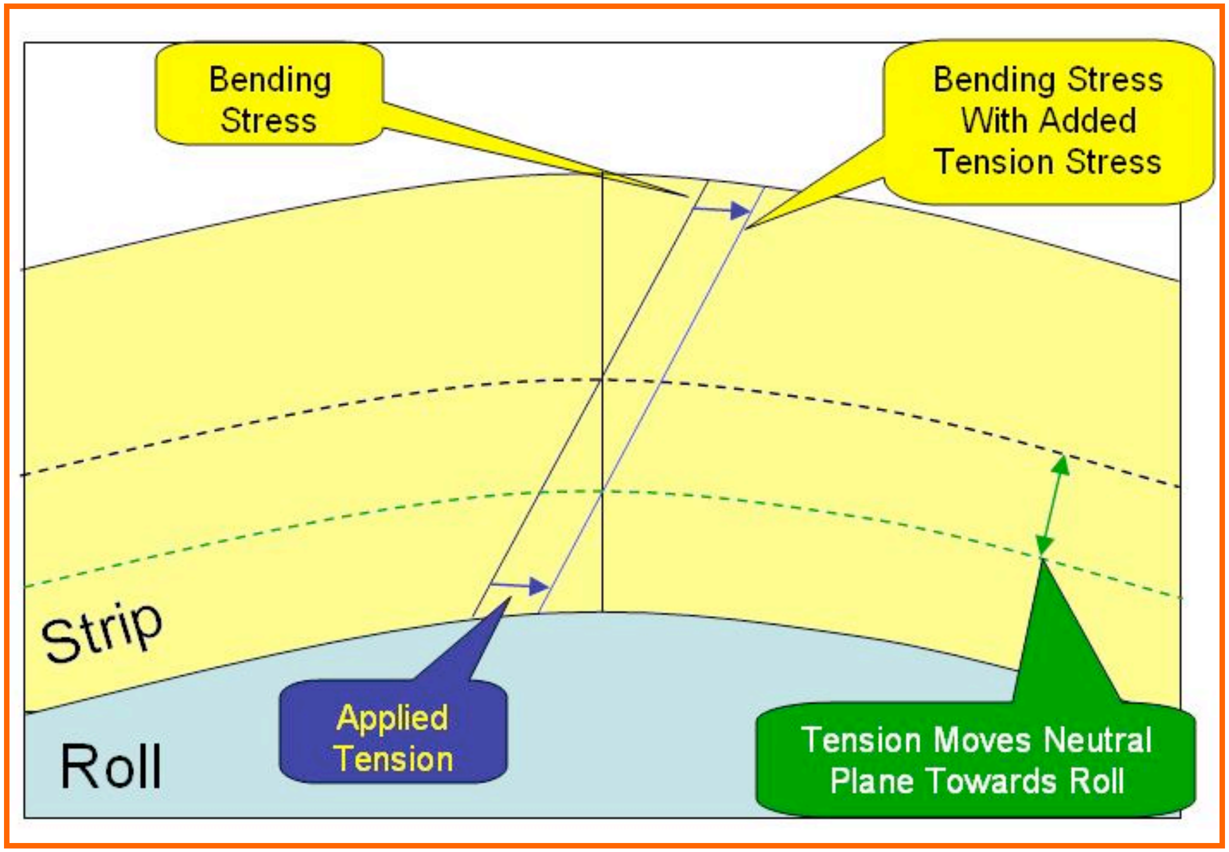
Small Diameter Tension Leveler Work Rolls Supported by Intermediate Rolls and Segmented Backups

Tension Leveling



In the case of strip being bent over a roll **without tension**, there will be a neutral plane located at approximately the center thickness position. Strip on the outside of this plane will be in tension and strip on the inside will be in compression.

Tension Leveling



When a strip is bent over a roll **with tension**, the neutral plane is moved closer to the roll surface. Consequently, more of the strip is deformed in tension.

Tension Leveling

What is Tension Leveling?

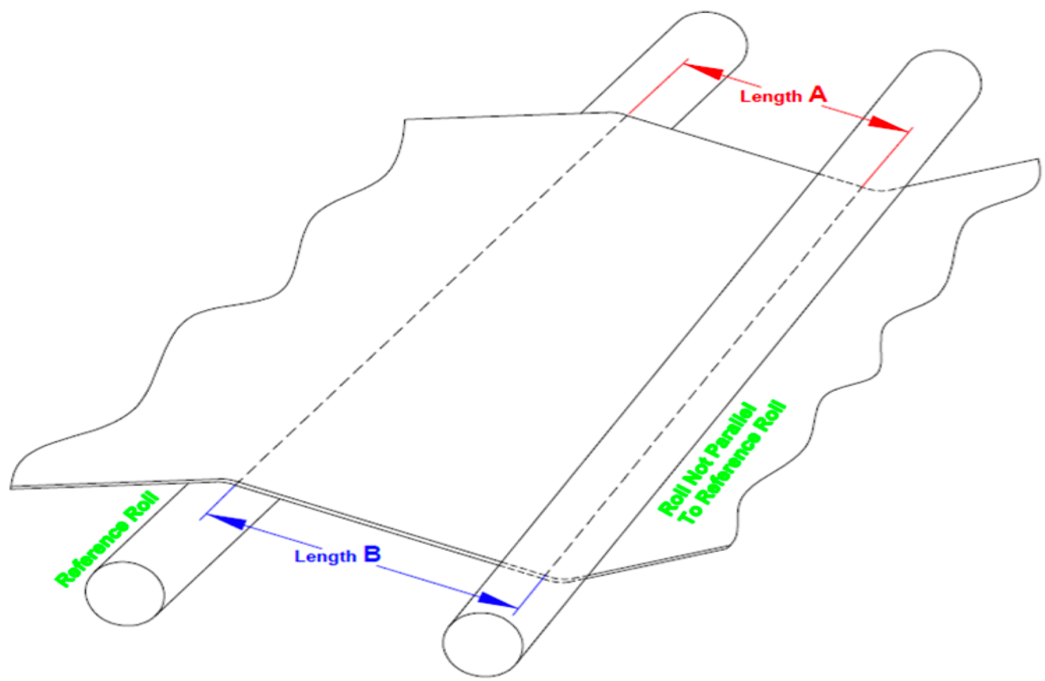
Shape correction capability

- The amount of elongation required can be calculated directly from the I-Units of shape.
  - 1% elongation removes roughly 100 I-Units of shape defect.
- Depending upon the rigidity of the tension leveler and the amount of elongation available, final strip shape better than 2 I-Units is possible

Tension Leveling

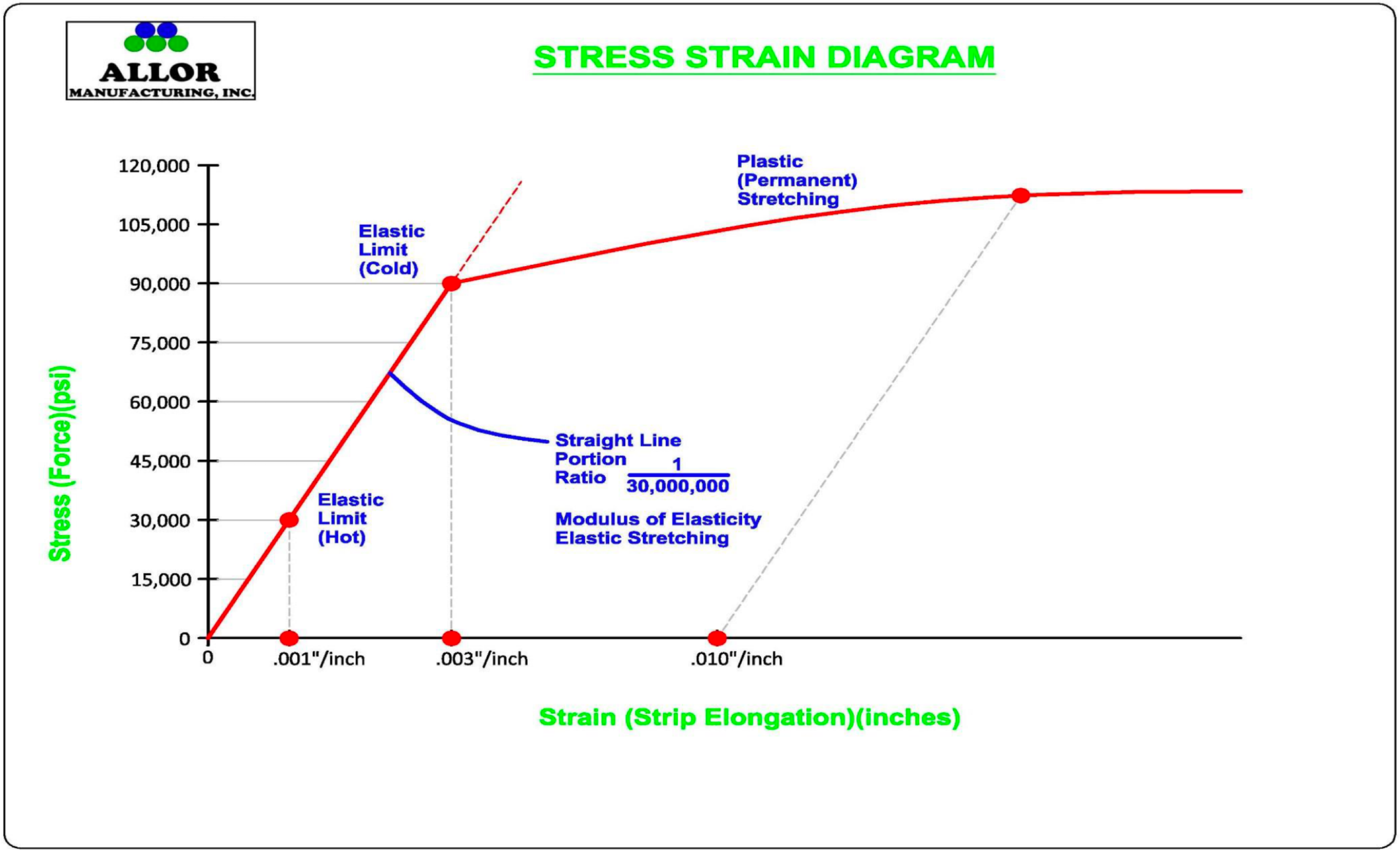
- All levelers depend on stressing the strip enough to permanently stretch out the irregular defects
- Plastic or permanent deformation only occurs after the metal is stretched beyond it's yield point

When two adjacent passline rolls are not exactly parallel, the length of strip between the rolls, at the edges, is not equal.



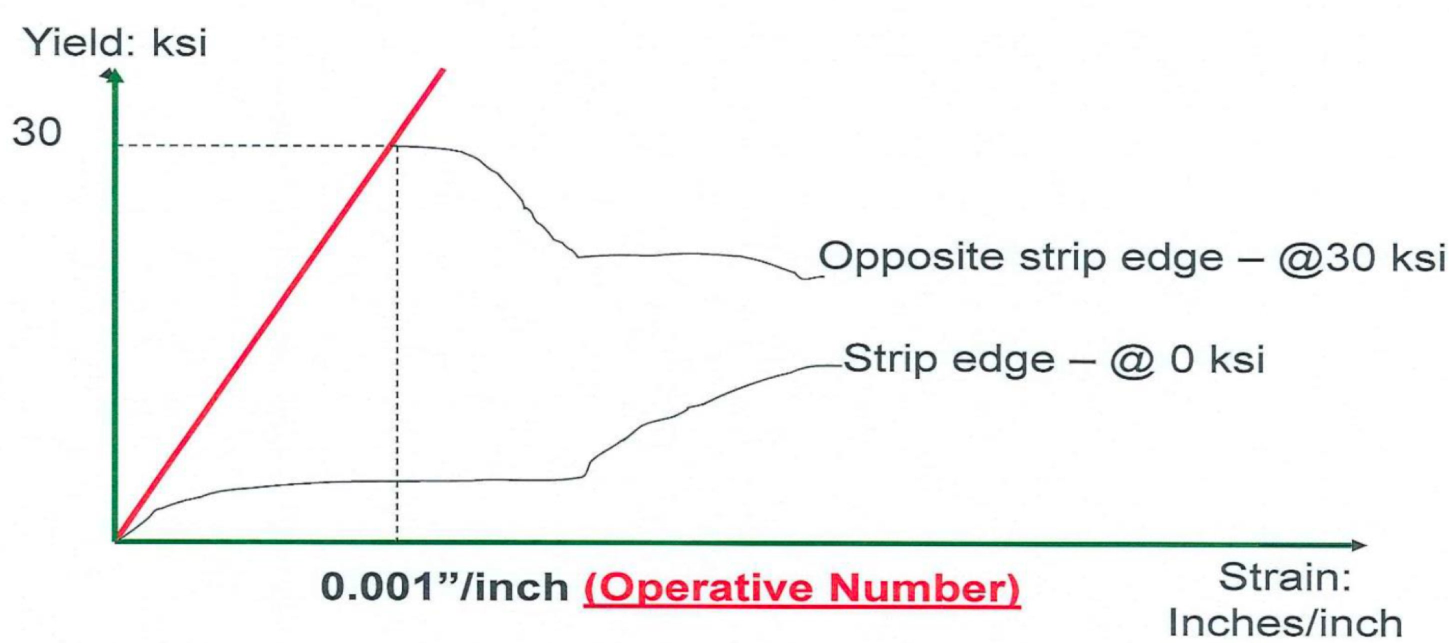
Rolls Not Parallel
Length (A) < Length (B)

Tension Leveling



Tension Leveling

If the Stress-Strain chart is applied to each end/edge of a strip and one edge is not stressed, the other edge *does not* get stressed beyond its elastic limit.



Tension Leveling

The key number from the previous slide is 0.001 inch/inch which is 30,000 (Elastic Limit)/30,000,000 (Modulus of Elasticity)

If the unsupported length of strip between rolls is known or measured.
That length times 0.001 inch/inch = equals the

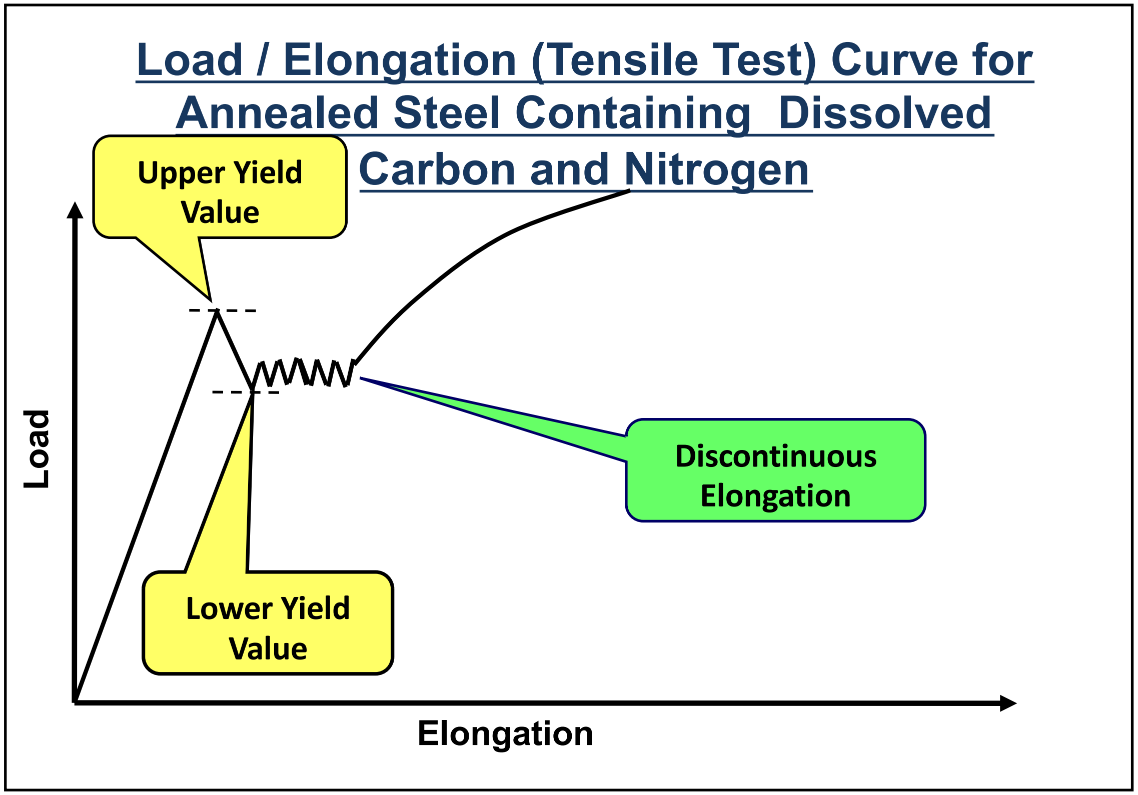
Maximum misalignment between the *ends* of the two rolls

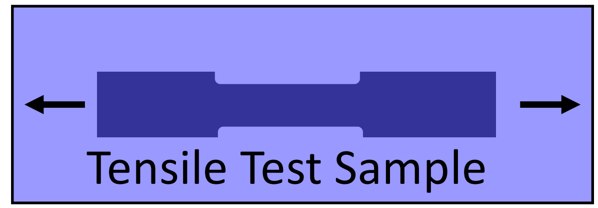
If that length is 2", the maximum roll misalignment should be
2" x 0.001 inches/inch = **0.002", or +/-0.001"**
(For strip with 60,000 psi elastic limit, the multiplier is 0.002"/")

Temper Rolling vs. Leveling

- When a strip is extended, say 1%, by temper rolling it is deformed by a combination of rolling reduction forces and tension forces
- In the case of leveling, the strip is extended by tension and bending forces
- In both cases the strip is 1% longer (and about 1% thinner), with discontinuous yielding having been suppressed
- Differences are:
    - TR gives a smoother surface with the cold work concentrated nearer to the surface
    - TL works the steel throughout the thickness and usually results in finely spaced leveler breaks
- No studies available on any differences that may exist between the formability and strain ageing characteristics

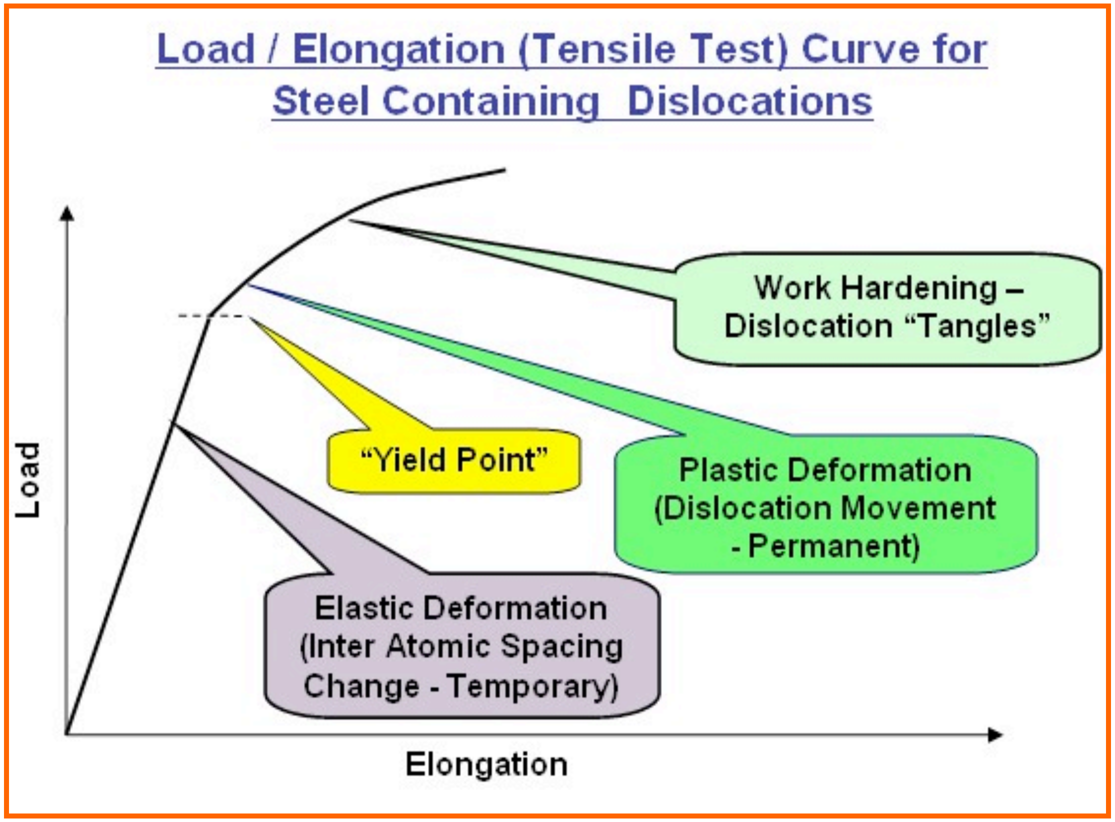
Discontinuous Elongation/Yielding





Carbon steels contain interstitial carbon and nitrogen, which during annealing migrate to preferred locations adjacent to dislocations - "pinning" them.
Yielding involves the onset of dislocation movement. When all dislocations are pinned, yield stress rises to a higher value required to create dislocations.

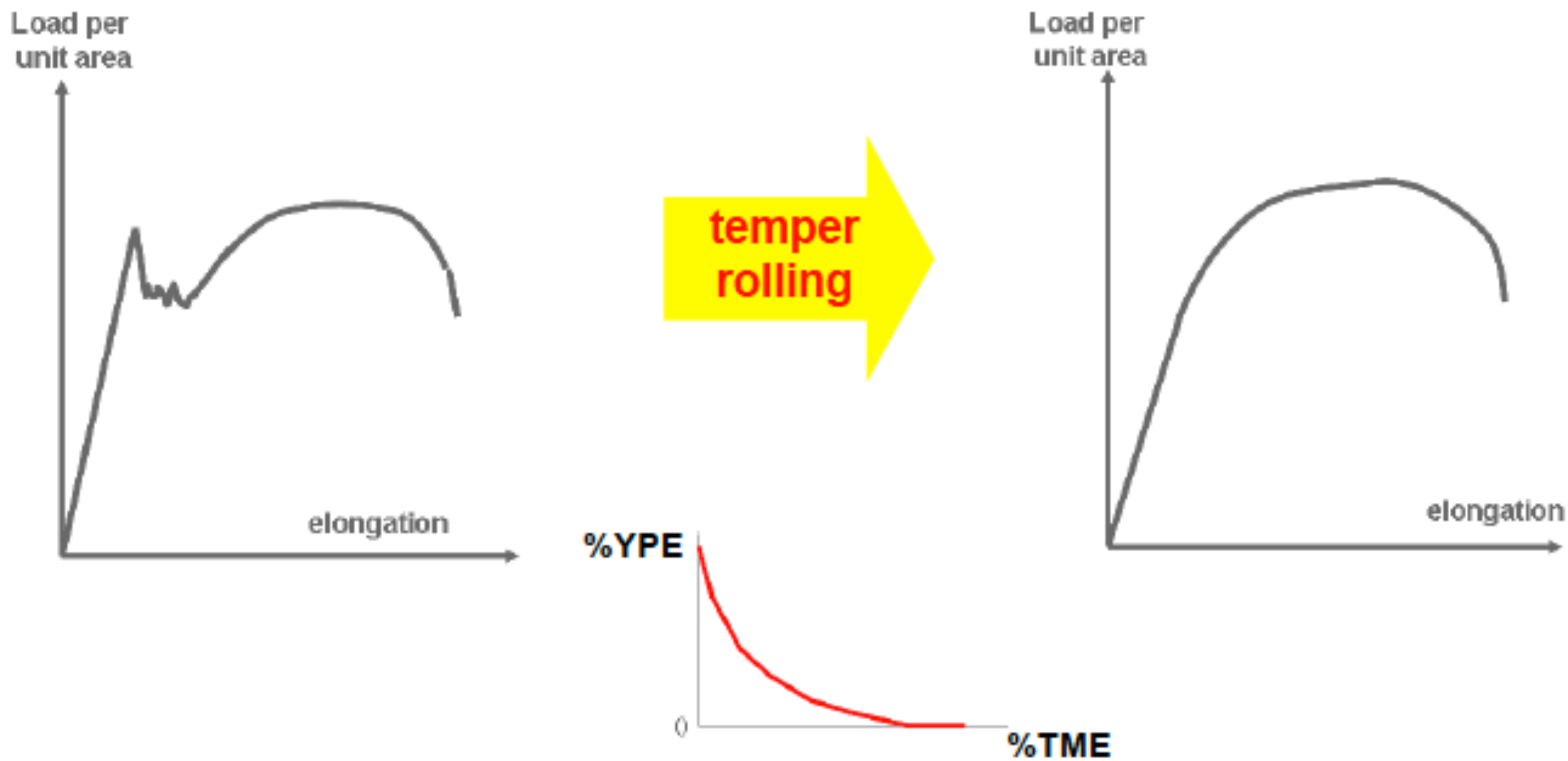
Discontinuous Elongation/Yielding



Temper rolling/leveling imparts enough cold work, i.e., high dislocation density, into the sheet to eliminate yield point elongation.

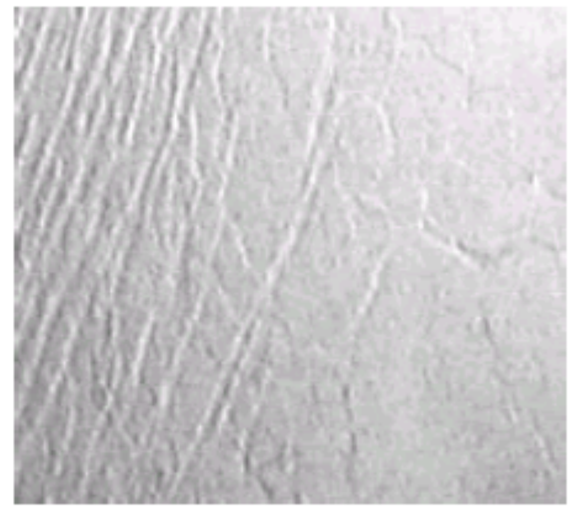
Discontinuous Elongation/Yielding

YPE is removed by temper rolling:



Discontinuous Elongation/Yielding

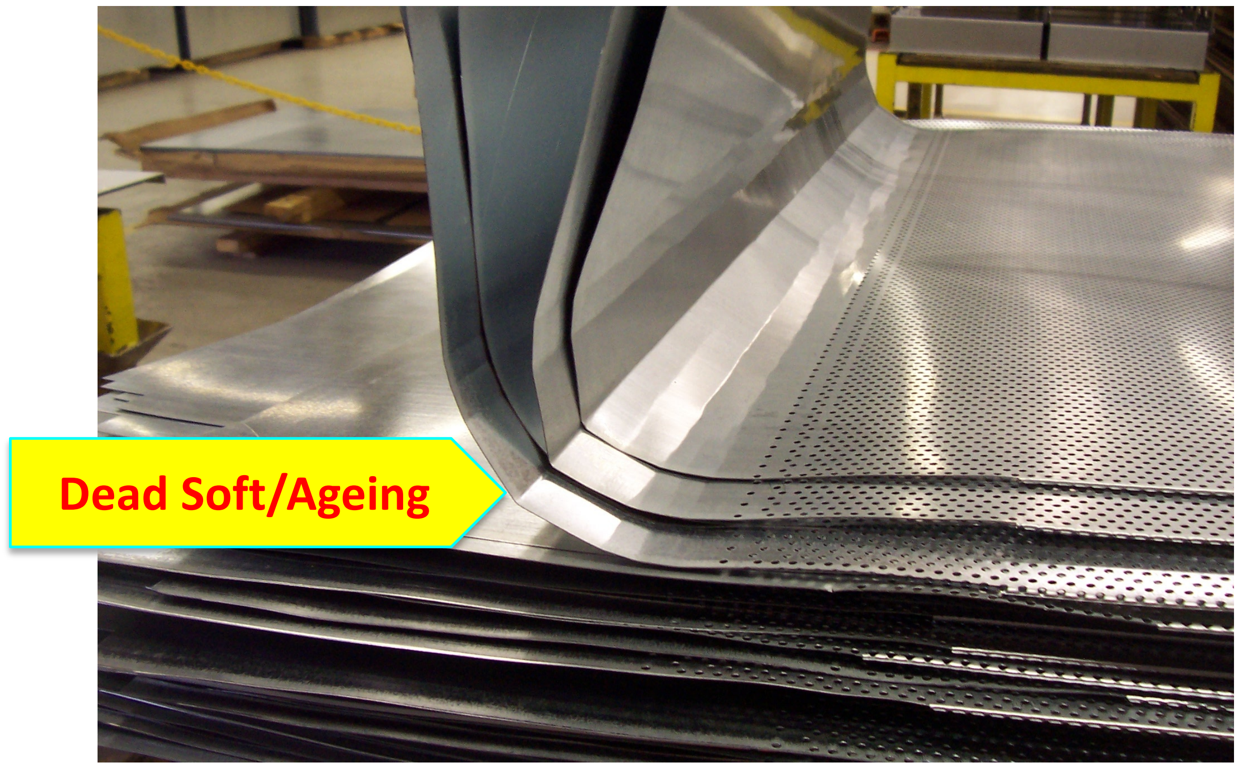
If YPE is not removed:



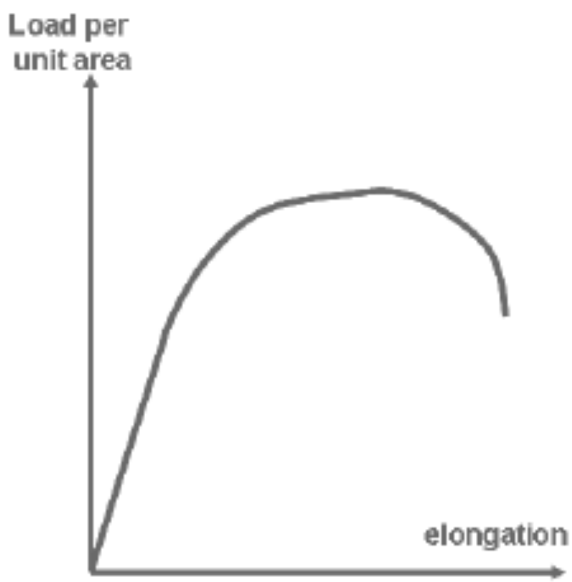
Lüder's bands or
stretcher strains

Discontinuous Elongation/Yielding

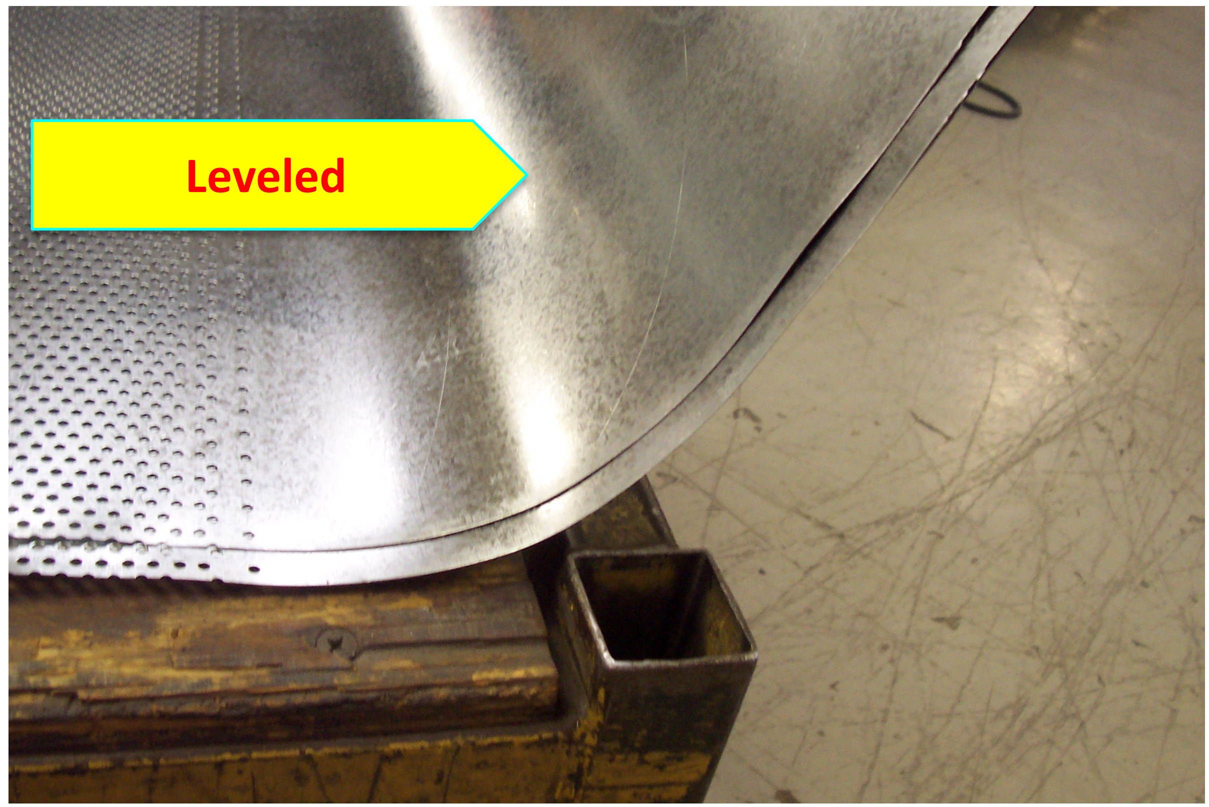
If YPE is not removed:



Discontinuous Elongation/Yielding



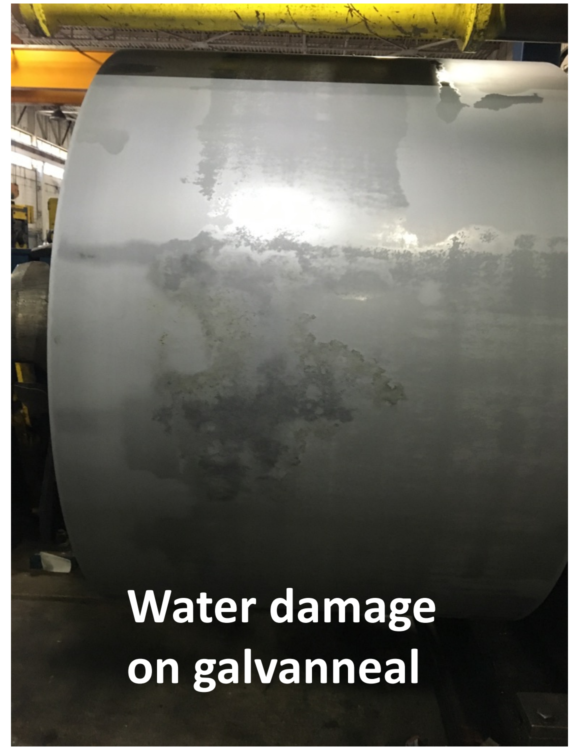
%TME



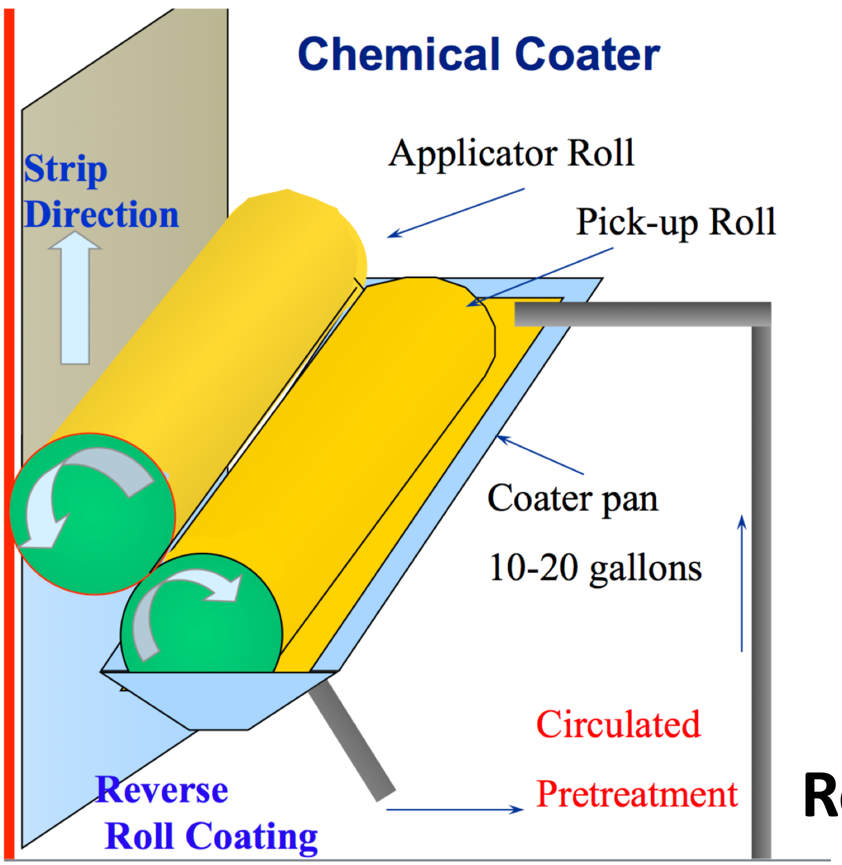
Chemical Treatment (Passivation)

- **Primary Objective:**
  - Prevent "Humid Storage Stain" or "White Rust"
  - Improve service life
  - Improve paintability
- **Secondary Objectives:**
  - Serve as a 'lubricant"
  - Maintain "brightness" of sheet in use
- **Types of Treatments:**
  - Chromate (Cr^{+6}) surface treatments (spray/squeegee or roll applied) – being phased out
  - Cr^{+3} and non-chrome surface treatments (spray/squeegee or roll applied)
  - Rust inhibitive oils
  - Acrylic & other polymer types – roll applied
  - Phosphates, etc., as paint pretreatments

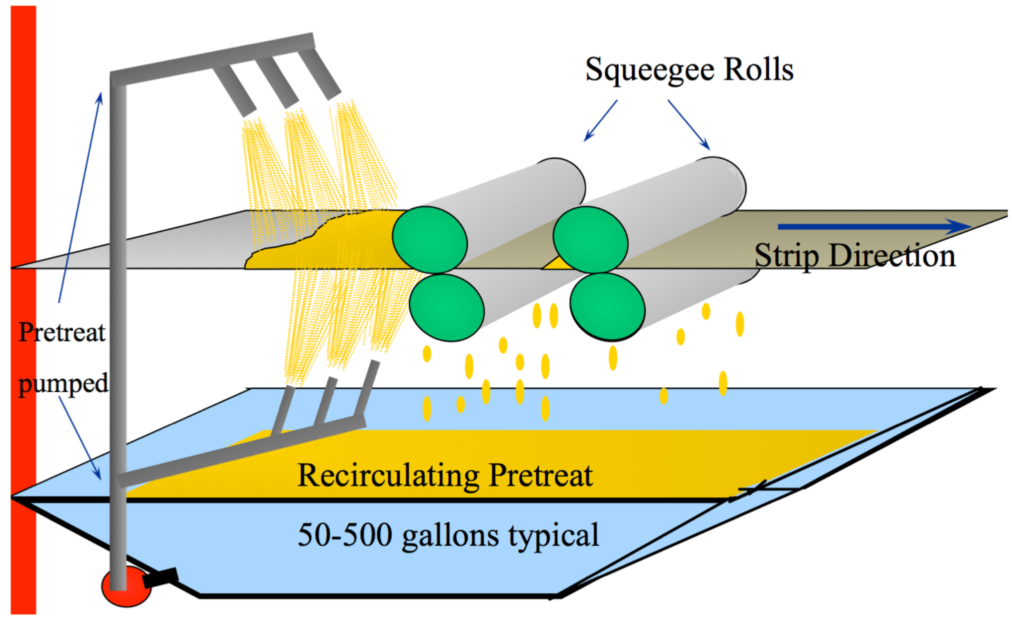
Storage/Water Stain – Various Forms



Passivation Application

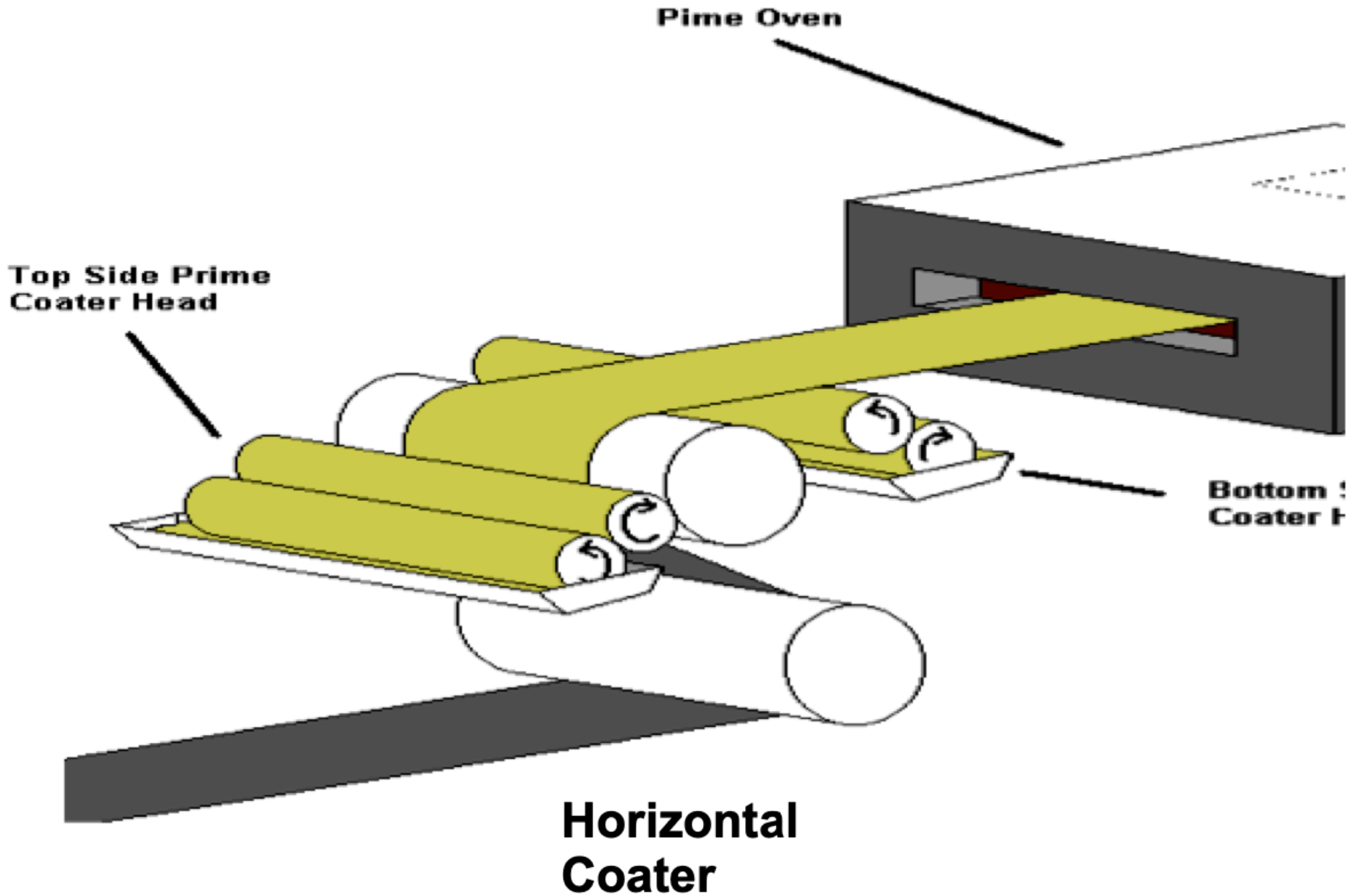


Reverse Roll Coating



Flood & Squeegee

Passivation Application



RoHS Compliant Treatments

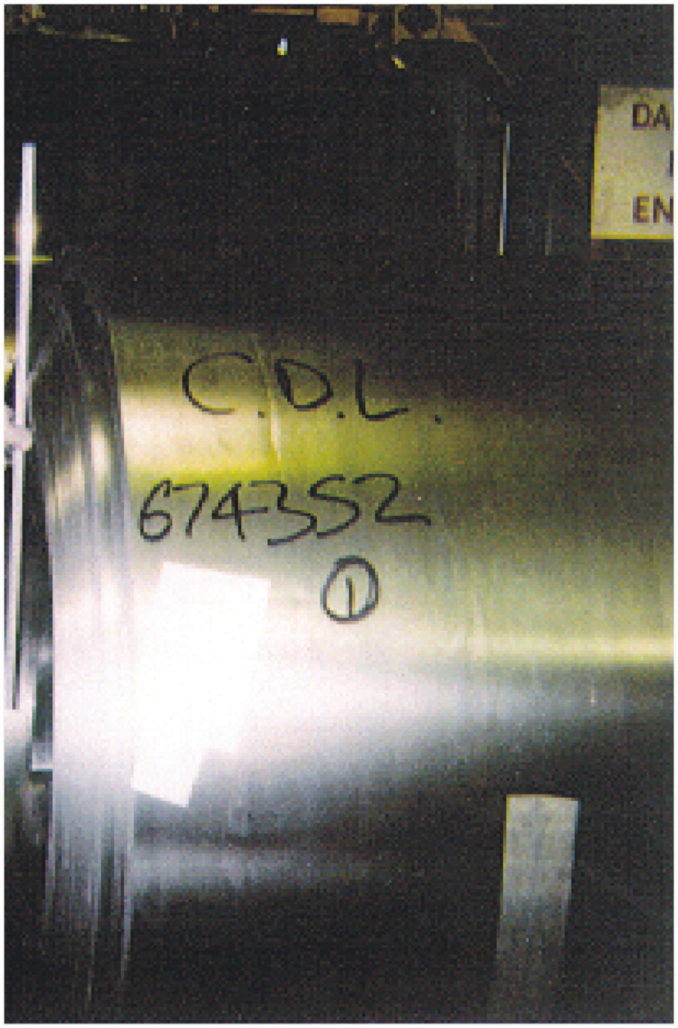
Producer	Product	Passivation Type	Comments
Quaker	PRIMECOAT Z 806 VF	Chrome-free	Up to 100 mg P/m^2
	PRIMECOAT Z 838/4	Trivalent chrome	Siloxane based
	PRIMECOAT TC 9001	Trivalent chrome	Thicker coating
Henkel	Bonderite M-NT 5400	Chrome-free	Paintable
	Bonderite M-PA 6000	Hex chrome-free	GI, GA, EG, AZ
	Bonderite O-TO 5080	Chrome-free	Organic coating
Chemetall	Gardolene D 6811 & 6812*	Trivalent chrome	Fluoride-free
	Gardotect TRP	Chrome-free	Removable
	Gardobond PC 4649/1	Chrome-free	TOC permanent

RoHS Compliant Treatments

Examples of USA Usage

Galvanizer	Treatment Product	Passivation Type	Comments
Company 1	Gardolene D 6812	Trivalent chrome	Paintable if cleaned
Company 2	Gardolene D 6811 & 6812	Trivalent chrome	Paintable if cleaned
Company 3	Bonderite M-PA 6010	Trivalent chrome	Not paintable
Company 4	Bonderite M-PA 6010	Trivalent chrome	Not paintable
Company 5	Bonderite M-PA 6010	Trivalent chrome	Not paintable
	PRIMECOAT Z 838/4	Trivalent chrome	Not paintable

Coil Winding

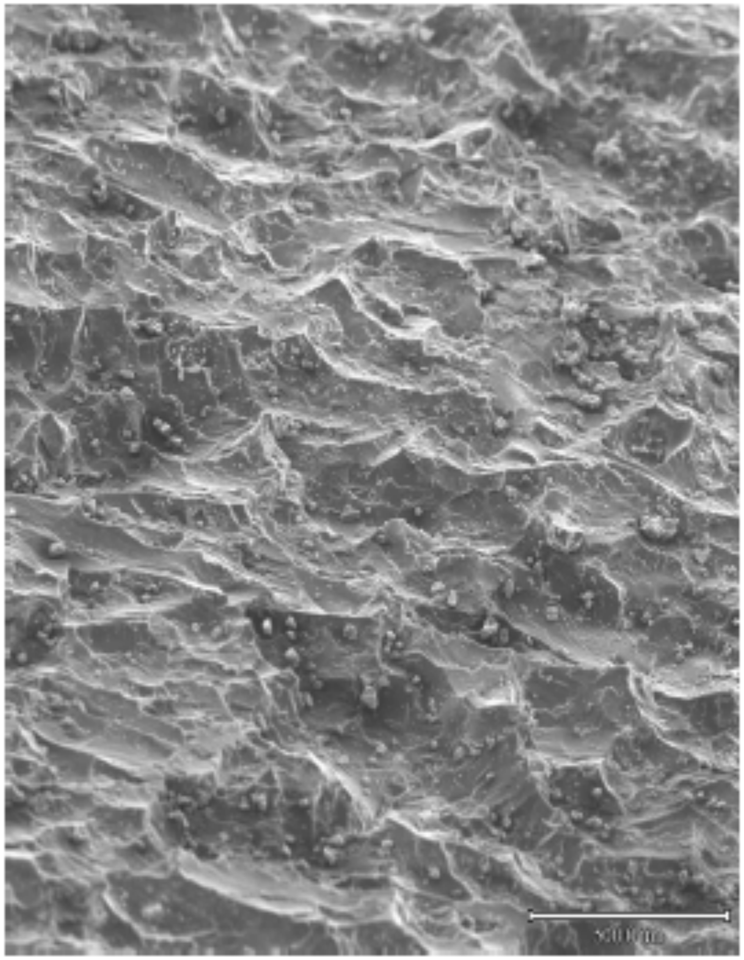


- Coil winding perhaps the most frequently performed process in the steel Industry
- Correctly wound coils have straight sidewalls and behave like a solid cylinder during subsequent handling and processing operations
- Also, the winding process should not incur friction defects due to internal slip, “buildup” or “ridge” conditions etc…

Coil Winding

- Frequently adjusted belt wrapper parameters are over-speed and wrapper pressure, but alone do not guarantee tight coil formation
- For a coil to “cinch” or pull tight, it is necessary for friction between the sleeve and the inside surface of the first wrap to exceed that between the wraps above – mandrel over-speed creates slip
- If slip occurs between strip wraps then the strip will progressively tighten onto the mandrel in a “clock spring” action until coiling tension is established
- If slip occurs first at the sleeve-to-strip interface, then the coil will never tighten and slipping will continue at this location until the coiling process is forced to abort

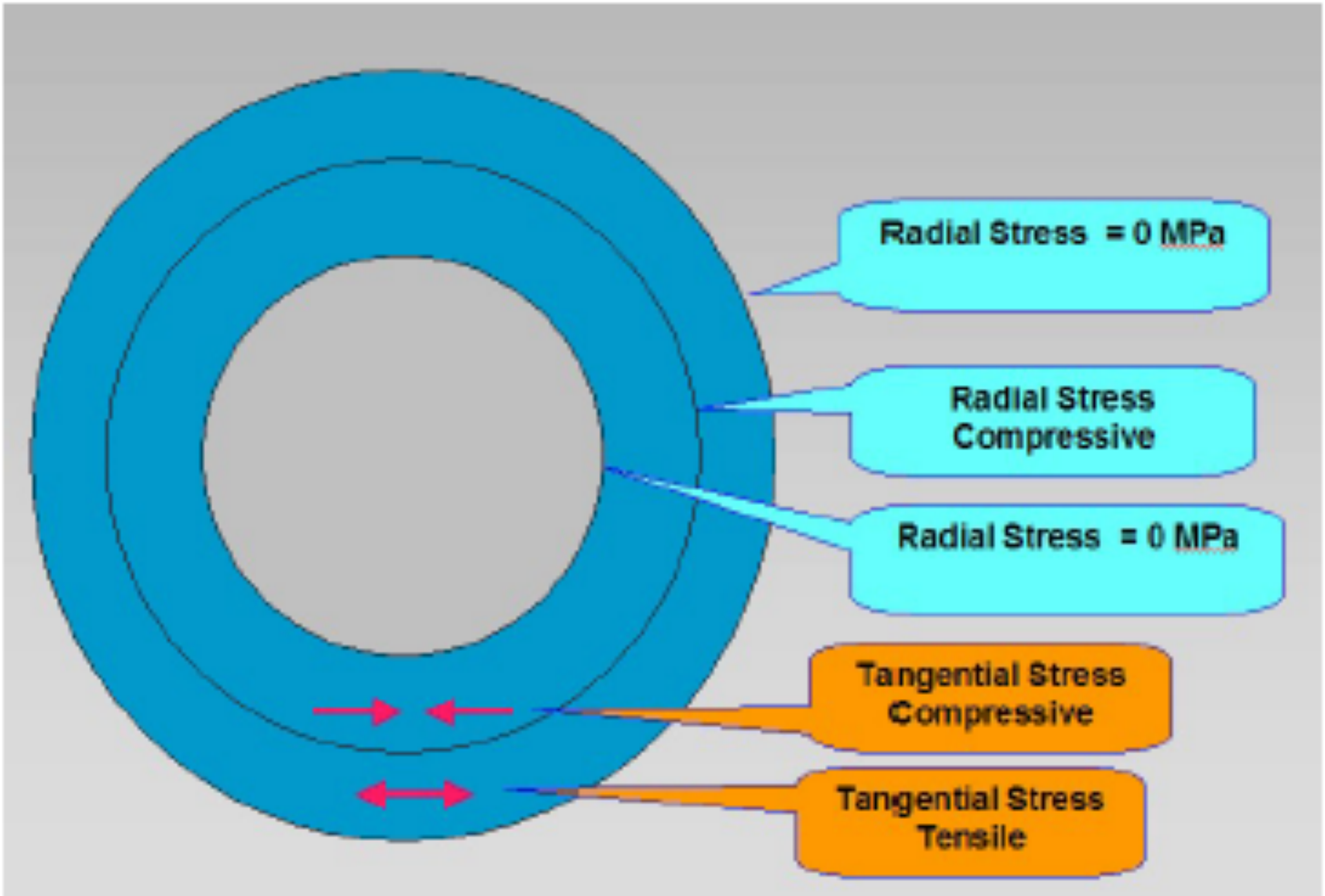
Coil Winding



Magnified Sleeve Surface

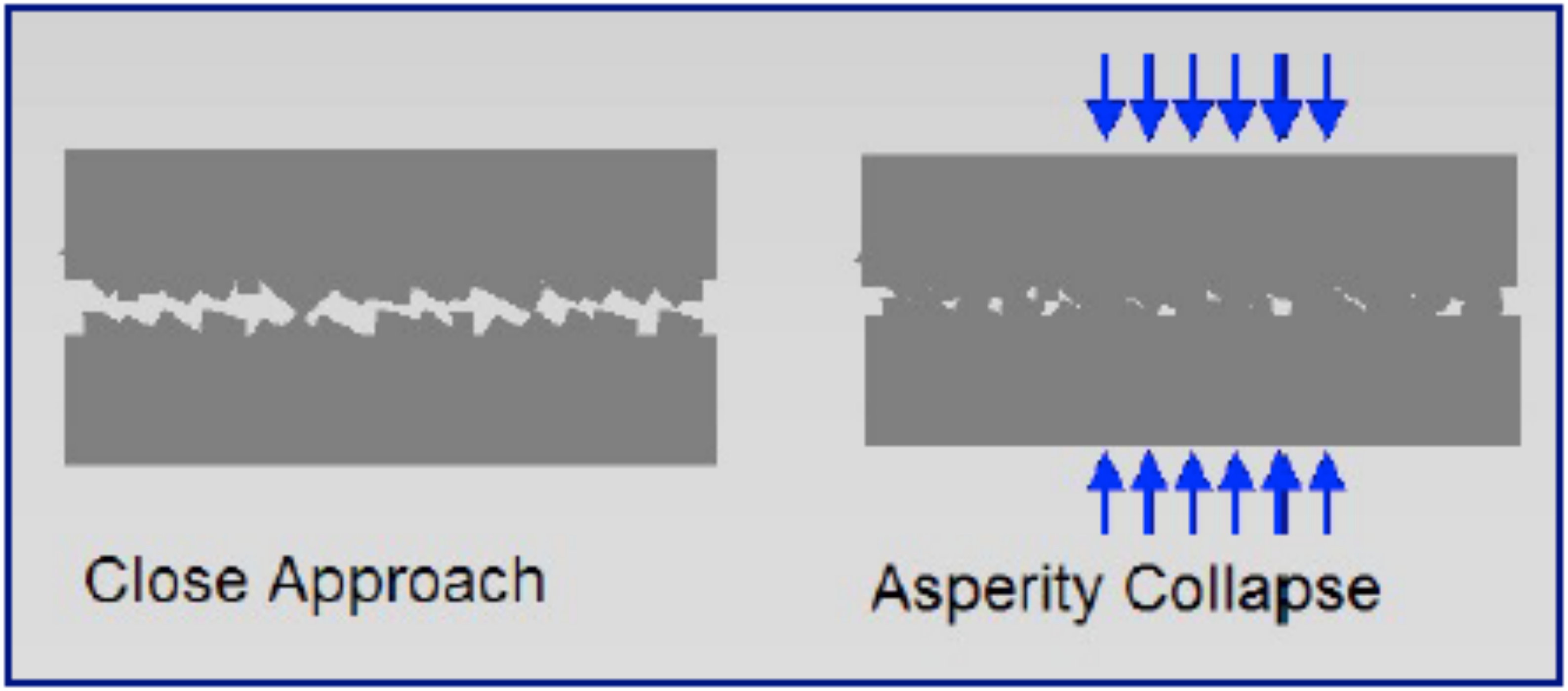
- The sliding friction coefficient of galvanized strip on galvanized strip needs to be in the range of 0.12 to 0.23, depending primarily upon the type/quantity of oil present
- The sleeve to galvanized surface friction coefficient can be high in case both surfaces are quite dry
- Increasing amounts of oil at this interface progressively decrease the friction coefficient, until it becomes dangerously close to that of strip on strip
- Sliding friction coefficient measured for solvent cleaned strip on similarly cleaned sleeve can be as high as 0.80, but reduces as low as 0.20 when a substantial quantity of oil is present

Coil Winding



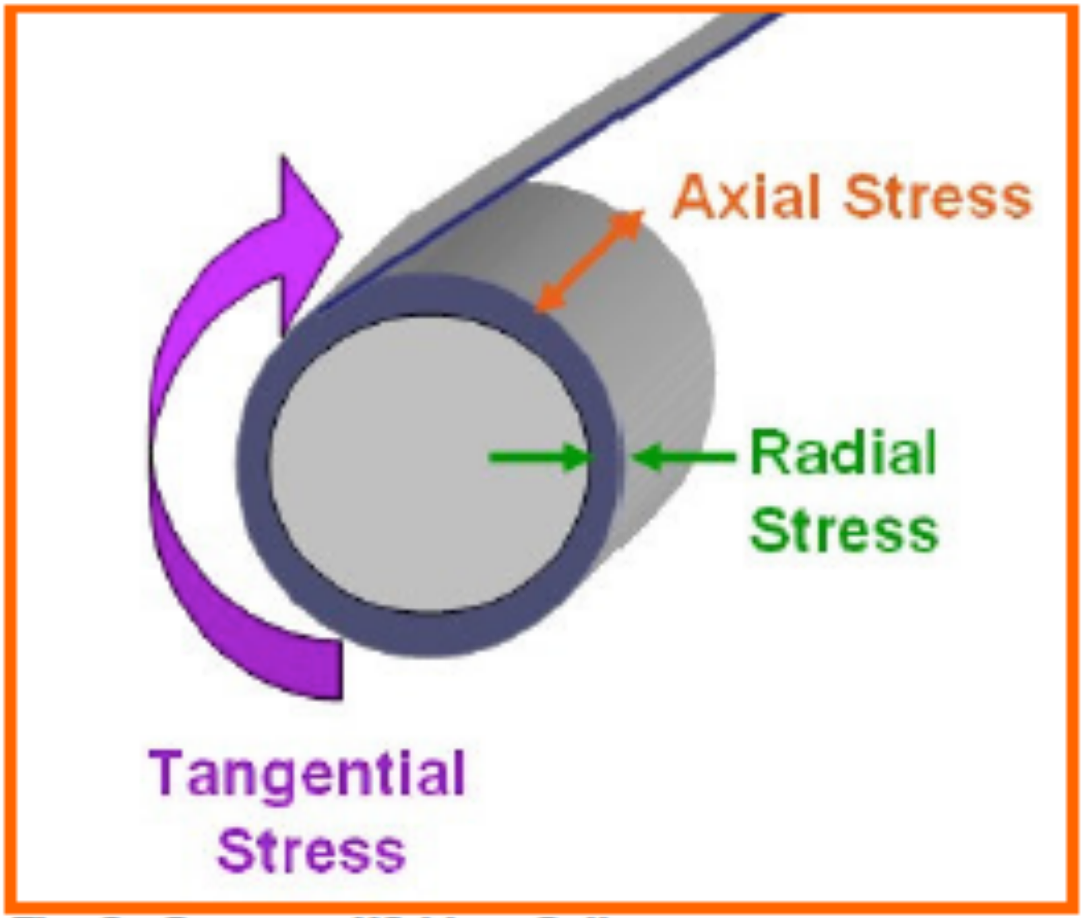
Stress Condition Within a Simple Two Wrap "Coil"

Coil Winding

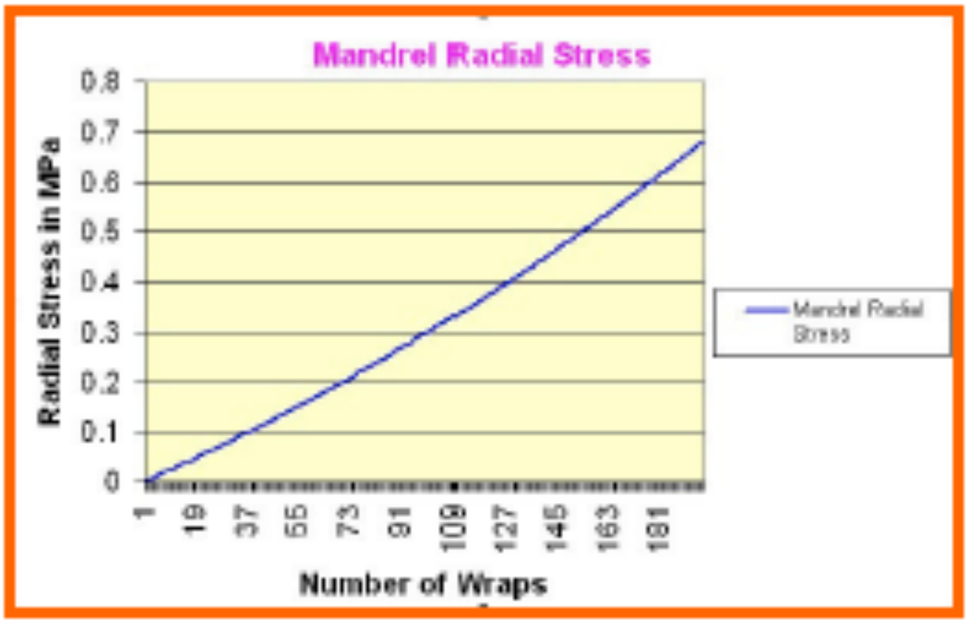


Asperity Collapse and Strip Compressibility

Coil Winding Stresses



Coil Winding Stresses



Calculated Radial Stress – Ideal Condition

- The radial stress resulting from the application of one wrap can then be calculated as...

  $$r(r) = - t(r) \times h \times r$$

  where : r(r) = radial stress
  t(r) = tangential stress
  h = strip thickness
  r = radius
- A 1.0 mm thick strip wound in 250 mm radius mandrel with a tension of 10.0 MPa creates a radial pressure against the mandrel surface of 0.0025 MPa
- Further wraps would build stress against the mandrel surface through the underlying wraps) in a progressive and almost linear manner

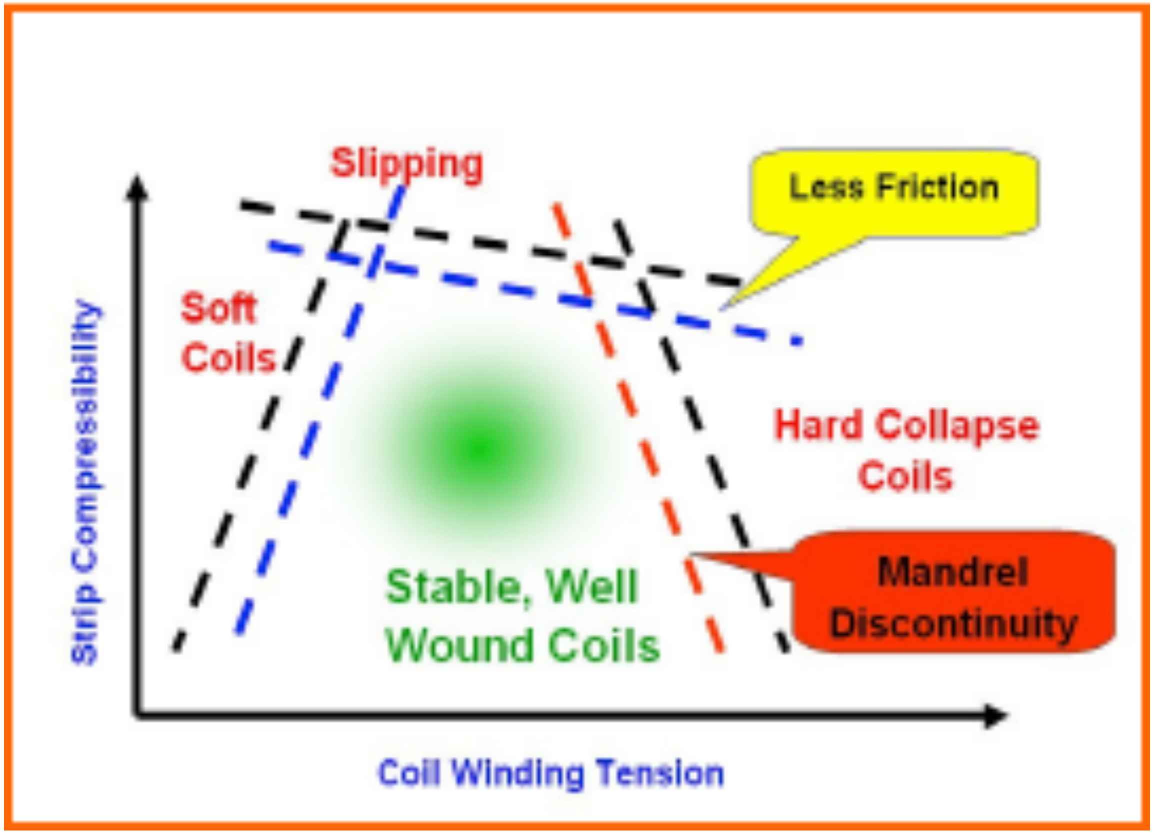
Coil Winding Failures

Slipping During Winding - with Consequent Telescoping

Coil Winding Failures

Soft Collapse

Optimum Coil Winding



Safe Area for Coil Winding

GalvInfo Center

A zinc-coated steel sheet technical information center managed by IZA and co-sponsored by the steel, service center, and zinc industries.