#31 ToolKit

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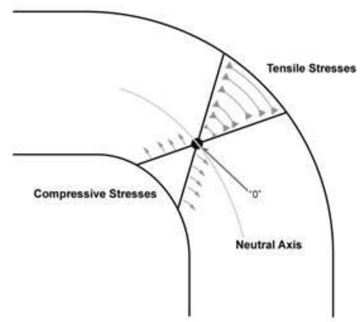
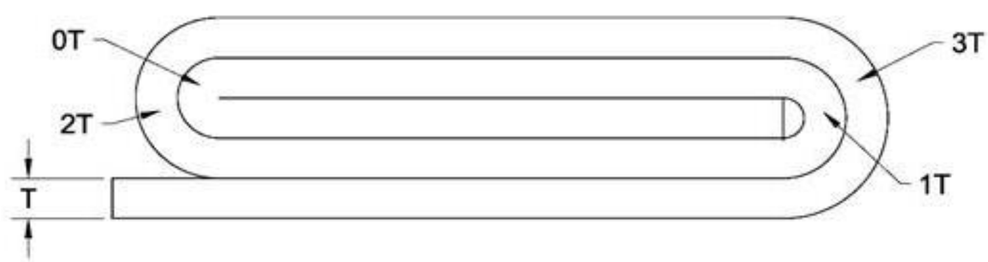
Percent Elongation of Coatings during T-Bend and 90° Bend Operations

In a sheet metal bending process, the material along the outer bend radius will be stretched, while the metal along the inner bend radius is going to undergo compression. Think of coil coated metallic-coated steel and aluminum—from a side view—as being composed of many infinitely thin layers of metal. The layer where compression ends and stretching begins is called the neutral axis or the neutral layer. The length of the neutral layer does not change during the bending operation, whereas the outer layer gets longer (stretches) and the inner layer gets shorter (compresses).



When testing the flexibility of prepainted metal, a T-bend test is routinely done. The figure below shows typical T-bends using NCCA nomenclature, where T is the thickness of the metal. The inner and outer bend radii are shown in the table below.

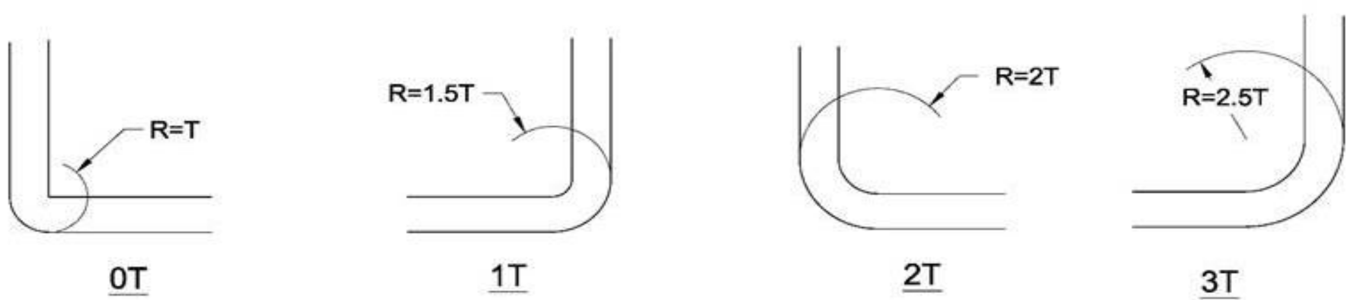


T-BEND	INNER RADIUS	OUTER RADIUS
0T	0	T
1T	0.5T	1.5T
2T	1T	2T
3T	1.5T	2.5T

NCCA describes the T-bend value as the number of layers of metal between the outer wraps of the bend. A 0 T-bend has the metal folded over on itself, whereas a 3T bend has 3 thicknesses of metal separating the upper and lower layers.

As the bend gets tighter (*i.e.*, 2T → 1T → 0T), we see more cracking and more inclination for pick-off, since there is greater elongation at the outer layer of the painted metal. The T-bend test is performed to determine if the painted metal system is flexible enough to withstand the fabrication operation, whether it is a roll-formed or brake-formed part.

When considering a 90° bend, there tends to be an assumption that all 90° bends are the same. This, however, is a misconception. Any bend can be described by either the inner radius of the bend, or the outer radius. Below are examples of four 90° bends with varying outer radii (expressed in terms of metal thickness). The equivalent T-bend value for each bend is also shown.



It can be important to know the amount of stretching that takes place at the outer layer of metal being fabricated, since this stretching is what the paint experiences during fabrication. It also may be important to calculate the T-bend equivalent of a bend, based on the inner radius of the bend and the metal thickness. A few equations may be used that describe this information (see **APPENDIX** for additional information):

$$\textbf{\% elongation of the outer layer} = 100 * 0.6T / (IR + 0.4T)$$

where T is the metal thickness, and IR is the inner radius measurement.[1] For example, assume a painted metal thickness of 0.020 inches, and an inner bend radius of 0.030 inches.

$$\text{\% elongation} = 100 * 0.6 * 0.020 / (0.030 + 0.4 * 0.020) = 32\% \text{ elongation.}$$

To calculate the T-bend equivalent of a bend:

$$\textbf{T-bend equivalent} = 2 * IR / T$$

[1] If you do not know the inner radius, but you do know the outer radius, use this equation to calculate the inner radius: IR = OR – T, where OR is the outer radius.

If you know the metal thickness and the inner radius[2], and you wish to determine the T-bend equivalent value, and using the same values above:

$$\text{T-bend equivalent} = 2 * 0.030 / 0.020 = 3T$$

Here is an example that many of us have encountered: A customer receives 0.030" prepainted HDG and successfully fabricates a part that has a 0.050" inner bend radius on a 90° bend. This customer now asks if there will be any problems if he switches to 0.056" HDG, while maintaining the same bend radius.

In the first example, the % elongation of the coating is:

$$100 * 0.6T / (IR + 0.4T) = 100 * 0.6 * 0.030 / (0.050+0.4 * 0.030)=29\% \text{ elongation}$$

When switching to 0.056" HDG, the % elongation of the coating is:

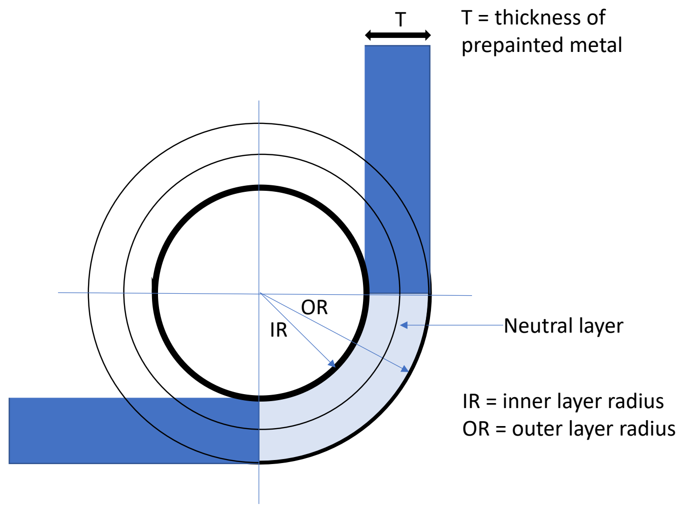
$$100 * 0.6 * 0.056 / (0.050+0.4 * 0.056)= 46\% \text{ elongation}$$

The coating may—or may not—be able to achieve 46% elongation. Even though the bend radius is the same, increase the metal thickness creates more elongation on the coating.

[2] To learn more about measuring the radius of a bend, see: https://www.wonkeedonkeetools.co.uk/radius-gauge/how-do-i-use-individual-radius-blades

APPENDIX

Consider the drawing below.



To understand how much elongation takes place at the outer layer, calculate the strain at the outer layer, where strain, ϵ, is the change in length at the outer layer, divided by the original length. The neutral layer—that layer than does not change its length during fabrication—is used as the original length of the outer layer before fabrication.

$$\epsilon = \text{strain} = (OL - NL) / NL$$

where OL = length of the outer layer, NL = length of the neutral layer, and where strain, ϵ, is expressed in decimals. Simply multiply strain by 100 to express strain in terms of percent elongation.

$$\%\ \text{elongation} = 100 * \epsilon$$

A circle's circumference is 2π times the radius. The length of the neutral layer, per the above drawing, is ¼ of the circumference of a circle made by the neutral layer radius, which is this circle's inner radius + 0.4 times the thickness of the prepainted metal.[3]

$$NL = \tfrac{1}{4} * 2\pi * (IR + 0.4T) = \tfrac{1}{2}\,\pi * (IR + 0.4T)$$

where NL is the length of the neutral layer in the bend region, T = the thickness of the prepainted metal, and IR is the inner radius of the bend.

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[3] The location of the neutral layer varies and is based on the material's physical properties and its thickness. For typical metals and metal thicknesses used in the coil coating industry, the neutral layer is very near the middle of the cross section of the sheet *if the inner bend radius is greater than 5T*. Expressed in terms of metal thickness, the neutral layer location on the cross section of a 5T bend would be 0.5T. For example, for a 0.020" thick aluminum or steel substrate with a 5T bend, the neutral layer is at the middle—0.010"—of the cross-section. For tighter bends, however, the neutral layer lies somewhat closer to the inside bend radius. ***For bends of 0T – 2T, the neutral layer lies about 0.4T from the inner radius.*** Using the example here, for a 0.020" thick aluminum or steel substrate with a 1T bend, the neutral layer is at a 0.008" point in the cross section (*i.e.*, 0.008" from the inner radius). Since a 2T bend is a very common requirement in our industry, the calculations discussed in the Appendix will use a neutral layer of 0.4T. For a 3T and 4T bend, the neutral layer is at 0.45T.

The outer layer of the painted metal (*i.e.*, the paint system), when subjected to a bend, stretches. The length of this outer layer is ¼ of the circumference of a circle made by the outer layer.

$$OL = \frac{1}{4} * 2\pi * (IR + T) = \frac{1}{2}\pi * (IR + T) \quad \text{(see note below)}$$

where OL is the length of the outer layer in the bend region.

The change in length of the outer layer during the bending operation is:

$$OL - NL = [\frac{1}{2}\pi * (IR + T)] - [\frac{1}{2}\pi * (IR + 0.4T)] = 0.3\pi T$$

To calculate the strain, divide the change in length (OL-NL) by the original length of the neutral layer (NL):

$$\epsilon = \text{strain} = 0.3\pi T / [\frac{1}{2}\pi * (IR + 0.4T)] = 0.6T/(IR + 0.4T)$$

and % elongation = $100 * \epsilon$

Note: Since the thickness of the coating is very thin compared to the thickness of the metal substrate, the coating thickness is ignored in the calculations. Only the metal thickness is considered, and this consideration simplifies the calculations.