The Principles of Tube Bending

Generally, bent tubes are used for structural (sometimes decorative) purposes or as passageways carrying fluids or gases.
Structural bent tubes: bicycle handlebars, furniture frames, grab bars, roll bars, etc.
Passageways: hydraulic lines, fuel lines, exhaust pipes, water lines, etc.

Industries typically using bent tube/pipes are automotive, aircraft, off-road and farm equipment, boiler, air conditioning, ship building, furniture, power generation, recreational vehicle, railroad, etc.

• How Tubes are Bent

When a tube is bent, the wall which forms the outside of the bend elongates and thins while the wall which forms the inside of the bend compresses and thickens.

A common objective in tube bending is to form a smooth round bend. This is simple when a tube has a heavy wall thickness and it is bent on a large radius. To determine if a tube has a thin or heavy wall, its wall thickness to its outside diameter is compared. The result is called the tube's wall factor.

$$\text{Wall factor} = \frac{\text{tube outside diameter}}{\text{tube wall thickness}}$$

The same type of comparison is made to determine if a bend radius is tight or large (D of bend).

$$\text{D of bend} = \frac{\text{bend centerline radius}}{\text{tube outside diameter}}$$

So, two ingredients - the wall factor and the D of bend - are used to determine the severity of a bend. As an example: a 2 in OD tube with a 0.200 in WT has a wall factor of 10.

$$\frac{2.0 \text{ in.}}{0.200 \text{ in.}} = 10$$

If the tube was bent on an 8 in centerline radius, the D of bend would be 4.

$$\frac{8}{2} = 4$$

In this case, an attractive bend can be formed with three basic tools: the bend die, around which the bend is formed; the clamp die, which grips the tube and holds it in position as the bend is formed; and the pressure die, which forces the tube into the bend die groove so it can be formed. Figure 1 illustrates the basic tools.

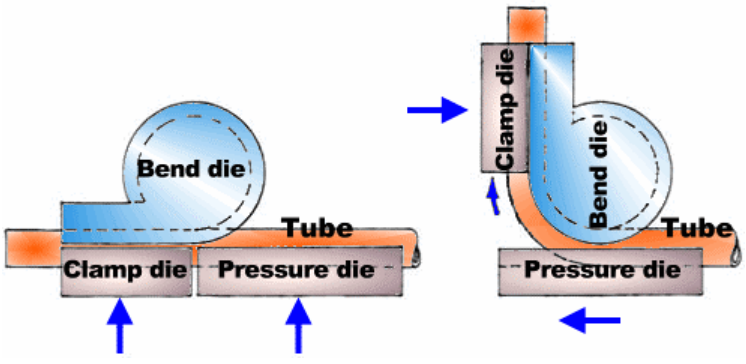

Figure 1. The basic bending tools showing prior and after bending

Unfortunately, all too often, bending requirements are not this simple. As the tube wall becomes thinner (the wall factor number becomes larger) and the bend radius tighter (D of bend number becomes smaller) a flat toned bend may result. This happens because the wall along the outside of the bend is not thick enough to support itself and collapses.

To prevent this a mandrel is required. The mandrel is placed inside the tube and supports it during bending. Mandrels can be either a simple plug type or a segmented ball type.
In the latter type the ball segments extend into the area of tube which is to be bent and flex with it during the bending process.

A tube with an outside diameter of 2 in. and a wall thickness of 0.100in. has a wall factor of 20. When bent of a 5 in. radius (2.5 D of bend) a mandrel with three ball segments would be required to form a smooth round bend.

If bending conditions become even more severe, for example, a 2in. OD tube with a 0.05in. wall (40 wall factor) were bent on a 4in. radius (2 D), a fifth tool, called the wiper die, would be required. (see figure 2)
It was said in this article that the tube wall along the inside of the bend compressed and thickened; but, when the tube wall is thin and the bend radius tight, as in the example above, it will not compress evenly, but will instead wrinkle.

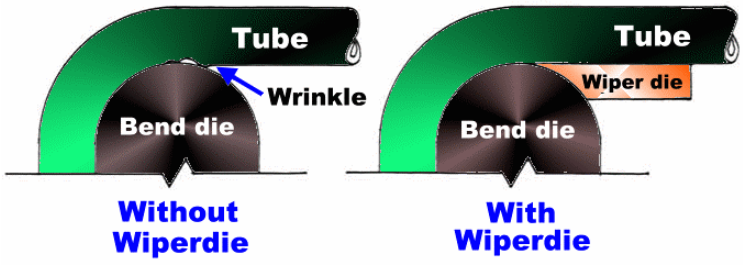

Figure 2: How the wiper die works

The wiper die is made so that it can nest in the bend die groove with its very thin tip extending to the bend tangent point (the point where the tube will begin to bend). In doing so, it fills up the gap normally left by the bend die. Therefore, the tube is completely confined and does not have space in which to wrinkle.

Elongation refers to the amount the material can stretch before it fractures. As was noted in the previous section, the tighter the bend radius, ie. the smaller the D of bend, the more the material will be required to stretch.

Usually product design's selection of material will be based on its end use. For example, stainless steel has a much higher percentage of elongation than mild steel; therefore, it is much easier to bend on a tight radius. But, if the end product is a bicycle handlebar, stainless is too costly and; therefore, mild steel would be selected.

The bend radius is also dictated by the end use, since it must create a shape which is functional and has aesthetic quality. Hopefully, the material which is selected and the bend radius which is chosen will be compatible.

• Common Bending Styles

There are several types of tube bending machines available today, each of which has its own particular advantage. Basically, three types are the 'work-horses' of the bending process.

• Press-type bending

The press-type bending machine is similar to a vertical press machine used in the sheet metal forming industry. Press bending is one of the oldest forms of tube bending. As with most vertical presses, power is transferred through a vertical ram cylinder to which a bend former is mounted. The bend former is 'rammed' into the wing dies which then give way to the force of the ram and wrap the tube around the bend former.

Press bending was very popular in the automotive exhaust pipe bending industry. In many instances an exhaust pipe manufacturer would set up a dedicated line of press benders.

Each bender would perform one bend of a multibend part and then be passed to the next machine. This process is still being used; however, due to the time necessary to perform a tool setup on a multiple press line, the cost of tooling, and new faster CNC bending equipment, this type of manufacturing is becoming less and less economical.

A disadvantage of the press bender is that a mandrel cannot be used. This has limited the machine to applications where out of roundness is not a critical factor.

• Compression-style bending

Compression benders were also widely used in manufacturing exhaust pipes. This type of bender resembles the draw type benders with the exception of the roller or 'wipe shoe' used to roll or wipe the tube around the forming die. The machine had limited success with mandrel bending.

The compression-style bending machine clamps the tubing to the stationary bend form and a rotating arm pushes the material around the bend form. (see figure 3)

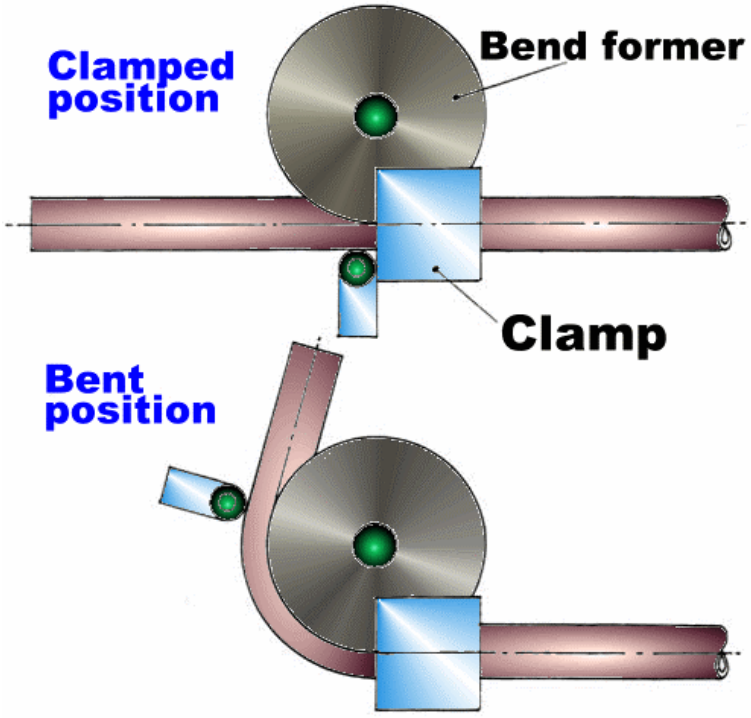

Figure 3: Compression-style bending

• Draw-style bending

Several manufacturers offer draw-style bending machines. This type of machine offers mandrel or compression bending.

The machine clamps the tubing to the bend former which then rotates, 'drawing' the material around the former.

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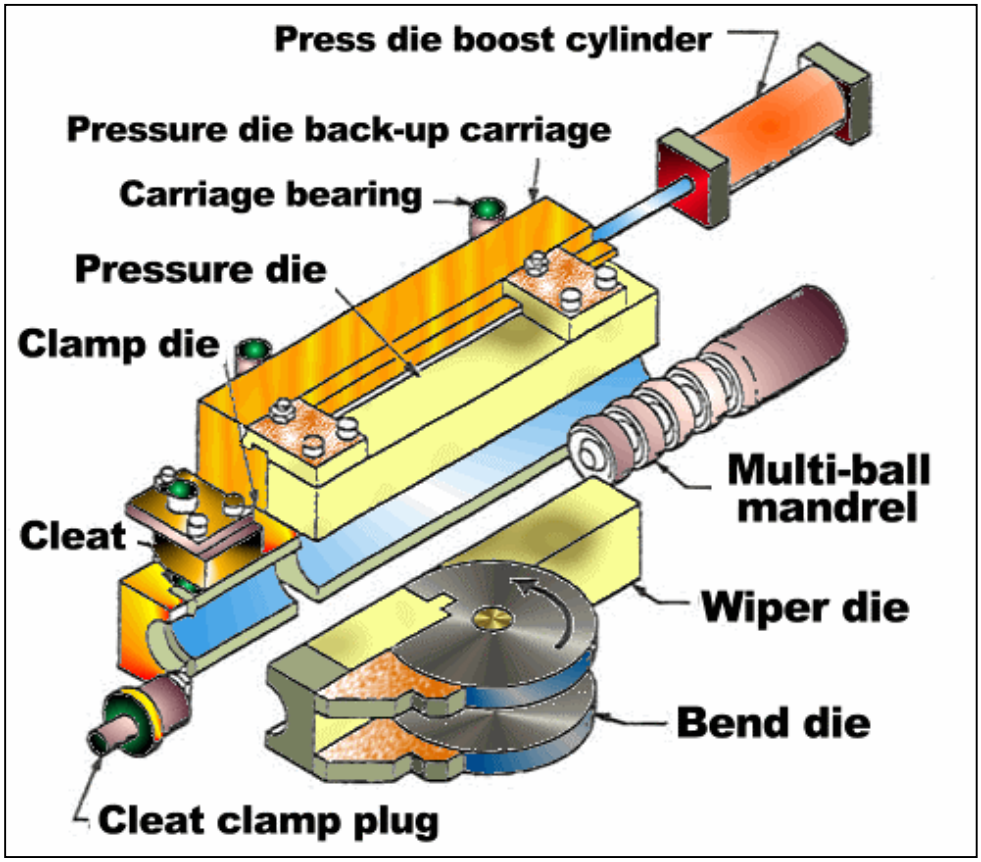
TOOLING DEFINITION

The types and designs of tooling commonly used in bending machines are shown below. The position the tools occupy in the bending machine are also shown.

- **Bend die**

The forming tool which is used to make a specific radius of bend is called a bend die. The bend die usually consists of two separate pieces called the insert and the bend radius.
The insert is used for clamping the tube to the bend die before forming. The bend radius forms the arc of the bend as the tube is drawn around the die.
The bend radius is normally sized to two times the tube diameter. Thus, a one inch bend on a two inch radius can be referred to as a 2D bend.
The insert used for clamping the tube normally has a 2D clamp length. Thus, a one inch tube with a two inch insert will have a 2D grip length.



- **Clamp die**

The clamp die works in conjunction with the bend die to ensure it clamps the tube to the bend die. The clamp die will move in and out to allow feeding of the tube.
Pressure die
The pressure die is used to press the tube into the bend die and to provide the reaction force for the bending moment. The pressure die will travel with the tube as it is being formed. The pressure die boost cylinder is attached to the pressure die. The boost cylinder can assist the tube through the bend to prevent tube breakage, wall thinning and ovality.

- **Mandrel**

The mandrel is used to keep the tube round while bending. The major components of the mandrel are the shank and balls. Mandrel balls are required when bending thin wall tube. Thicker wall tubes may be bent with compression tooling (elliptical type) or bent using a plug mandrel.

- **Wiper die**

With mandrel bending, it is sometimes necessary to use a wiper die. This is used when a mandrel alone will not prevent wrinkling while bending a tube. The wiper die “wipes” wrinkles from the tube. It mounts directly behind the bend die.