4.6 THIN-WALLED WELDED STEEL TUBE FORMING

Seam welded cold-rolled steel tubing can be an alternative to assemblies of two stamped shells welded into tubular structures. The tubing can be mandrel/die bent and may be additionally formed to the desired shape hydraulically. Typical pre-formed cross sections used in structural automotive parts are circular and rectangular.

Several processes are employed for forming tubing. The selection depends on the complexity of the end product.

- When only reorientation of a constant section is required, the tubing is bent.
- When more than reorientation of a constant section is needed, the bent section can be locally compressed in an open cavity.
- When more complex reshaping is needed, the bent tube can be placed in a closed die set where a pressurized fluid is introduced into the ends of the tube, reshaping it to the confines of the cavity, in a process known as hydroforming.
- If more shape changes are needed, hydroforming can be performed at higher pressures or be combined with compression bulge forming.

Following is a description of these processes, starting with tubing fabrication and progressing from the simplest to the most complex reshaping processes.

4.6.1 FABRICATING THIN WALLED STEEL TUBING

Thin walled steel tubing for automotive applications is fabricated in a high speed, continuous process. The type of steel selected depends on the requirements of the application and the forming process. Tubing for hydroforming is typically made from 1008-1010 aluminum killed steel or medium strength HSLA steel, either in ASTM half-thickness tolerance hot rolled or ASTM regular-thickness tolerance cold rolled coils. The sheet is slit to a strip of width required for the perimeter of the tubular section. The strip then passes through rolls where it is formed into a closed circle, and the edges are welded either by a high frequency butt or TIG weld as shown in Figure 4.6.1-1.

The rough weld joint may then be cleaned up. Normally only the outside is cleaned up unless subsequent processing utilizes mandrels that require a smooth inner surface. The tubing may also be annealed, depending on the material. The tubing is then longitudinally stretched or circumferentially compressed to precisely set the outer perimeter. If another shape, such as a rectangle is required, the round tube is rolled to the new shape. If the steel is bare, the tubing is pickled and oiled. Finally, the continuous tube is cut into straight, finite lengths for further processing, and washed clean of cutting fluids and chips.

The steel coil is processed into tubing at either a steel processing plant or a tube fabricating facility. The added processing cost, which depends on the number of finishing operations, typically ranges from \$0.11-0.22 per kg (\$100-200 per ton or \$0.05-0.10 per pound).

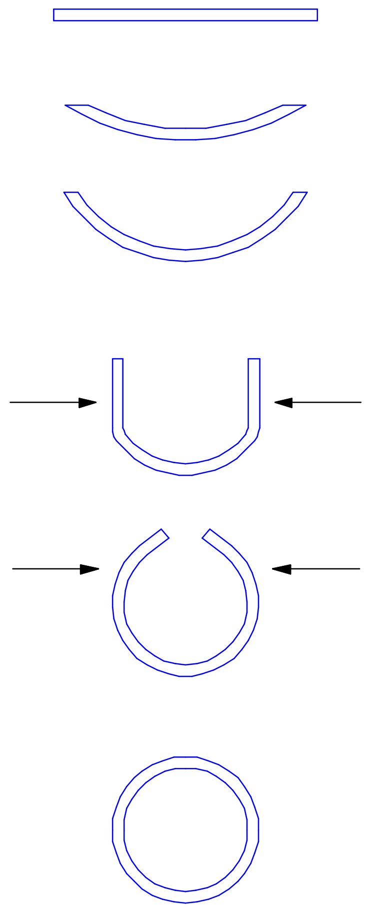


Figure 4.6.1-1 Tube forming process

4.6.2 MANDREL OR DIE RESHAPING OF TUBULAR SECTIONS

If a tube with a constant cross section of various orientations is sufficient, a bent or twisted tube is the most economical solution, sometimes with the addition of local smashing, as shown in Figure 4.6.2-1. Processing is performed in high speed tube benders. Instrument panel support bars and utility vehicle frame rails are examples of these applications.

Tube bending limits are driven by necking or thinning constraints on the outer wall; the forming limit of the material must not be exceeded. Therefore, a forming limit diagram for a particular steel may be required. To estimate bending radius limits:

- Assume a neutral axis located one third the section height from the inside diameter.
- Calculate the elongation of the outer fibers after bending.

Wrinkling may also occur on the inside of the bend if the inside bending radius is too small. This may also be a forming limit or product stability limitation for sections with a low ratio of thickness-to-diameter[1]. NC feedback controlled bending of tubes tends to produce better dimensional repeatability than stamping and post-welding. In some cases, NC bent-and-drilled structure sub-parts have been so repeatable that clamping and control points have been minimized on the final assembly fixtures.

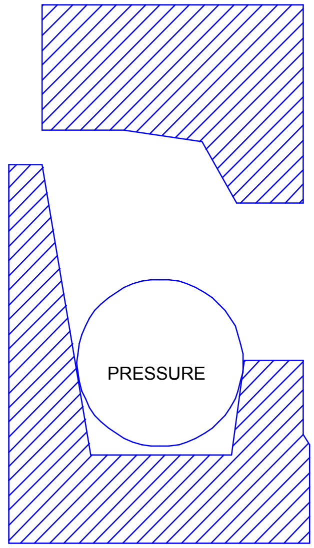


Figure 4.6.2-1 Local tube compression

4.6.3 DIE BENDING

If a straight tube can be dropped into a tubular width cavity, the part can be reshaped in a single plane die-and-punch operation. The process allows limited reshaping of the perimeter, punching of holes and local compression. It does not require special tube bending equipment.

4.6.4 HYDROFORMING

Processing techniques for hydroforming were originally patented in Japan in 1962. The process was initially restricted to a few part suppliers. After the patents expired, the process reappeared and matured in the pipe fitting industries. It is relatively new to the automotive body, exhaust and chassis structure industries. The process is divided into two principal types: low pressure and high pressure. A typical setup for hydroforming is shown in Figure 4.6.4-1.

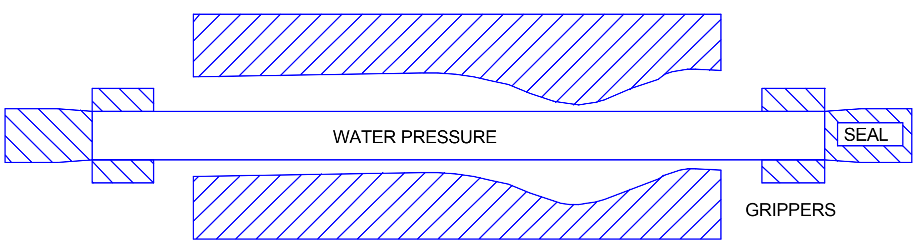


Figure 4.6.4-1 Typical hydroforming setup

4.6.4.1 Low Pressure Hydroforming

If a constant perimeter length (less than 5 percent expansion) with reshaping will satisfy the product needs, or if greater dimensional control is needed than for die struck parts, low pressure hydroforming of die bent or mandrel bent tubes is a low investment process. Cycle times are slightly longer than for a bent or mechanically formed tube, and shorter than for a high pressure process.

Low pressure hydroforming is arbitrarily defined by the Tube and Pipe Fabricators Association as a process using fluid at pressures less than 83 MPa (12,000 psi). The fluid is typically water with a rust inhibitor. A complete cycle consisting of preform loading, forming, depressurizing and unloading ranges from 15 seconds to more than a minute.

A companion process, called pressure sequencing, is used at the same pressure range. It consists of applying a pre-pressure, and varying the applied pressure as the dies are closed.

The preform consists of a straight, bent, twisted or locally deformed tube. Die splits must be designed to allow the preform to drop into the cavity and the finished part to be extracted from the cavity. The preform must have sufficient dimensional repeatability to drop readily into the hydroforming cavity; conversely, the dies must be able to tolerate the expected variations in the preforms. The design limits of the cavity split lines for insertion of the preform into the hydroform cavity may limit the final complexity of the finished parts.

Forming pressures less than 28 MPa (4000 psi) generally produce one percent perimeter expansion or less, and sections with nearly equal wall thickness. Perimeter expansion is governed by yield strength, work hardening and initial wall thickness as well as pressure. Forming pressures above 28 MPa (4000 psi) are used for parts that require more consistent forming beyond the yield strength, and perimeter stretching up to five percent. Normally, the higher the applied pressure, the higher the initial investment for tooling, hydraulic interfaces to the tubing, and pressurizing equipment. Both pressure levels seem to equalize the strain over the entire part and improve part repeatability beyond that of NC controlled bent parts.

A hydroforming die set generally requires only one pair of dies. The amount of die wear, and consequently the required die maintenance, depends on the extent to which the metal being formed slides over the die surfaces. Press platens are used to bring the dies together; in some cases the dies form the tube to some extent as they close, as implied in Figure 4.6.4-1.

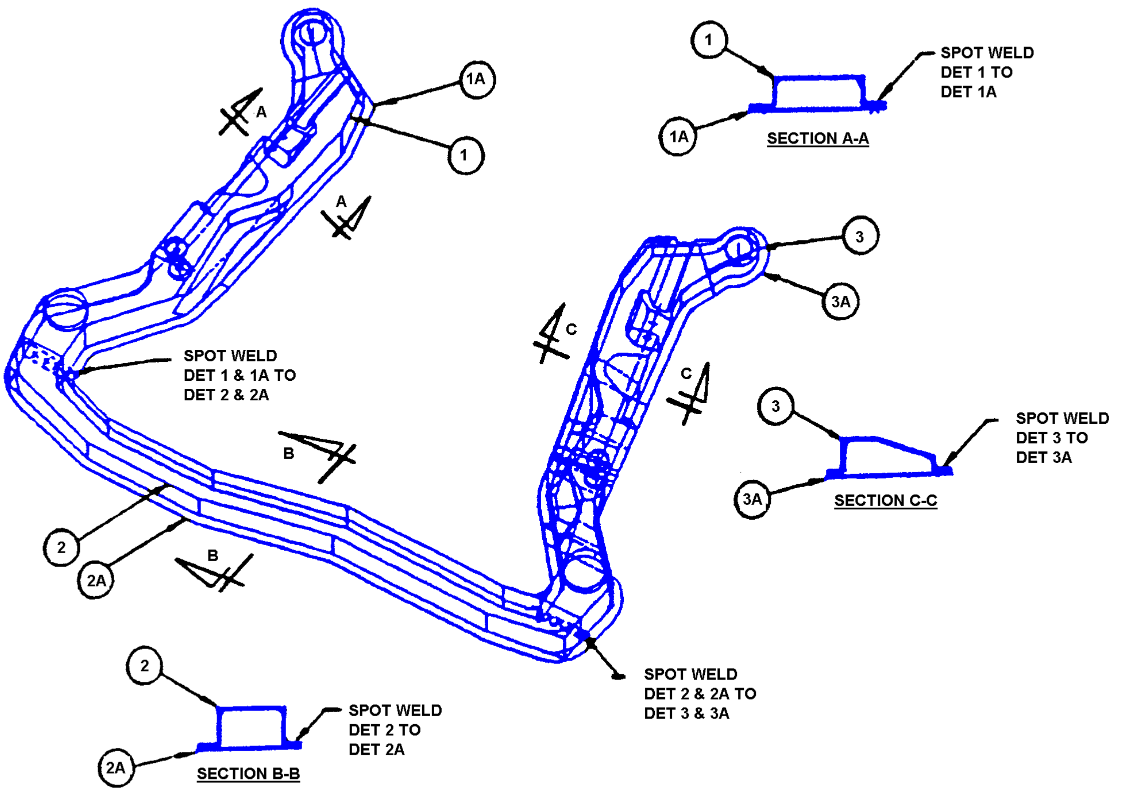
End-of-tube hydraulic fittings are typically unique to the processor or are proprietary. As the forming pressure increases, the sizing and condition of the ends of the tubing become more critical.

After the part is formed and any post end-of-tube treatment is completed, a portion of tube ends may be removed. These operations normally generate less engineered scrap than does conventional stamping processes.

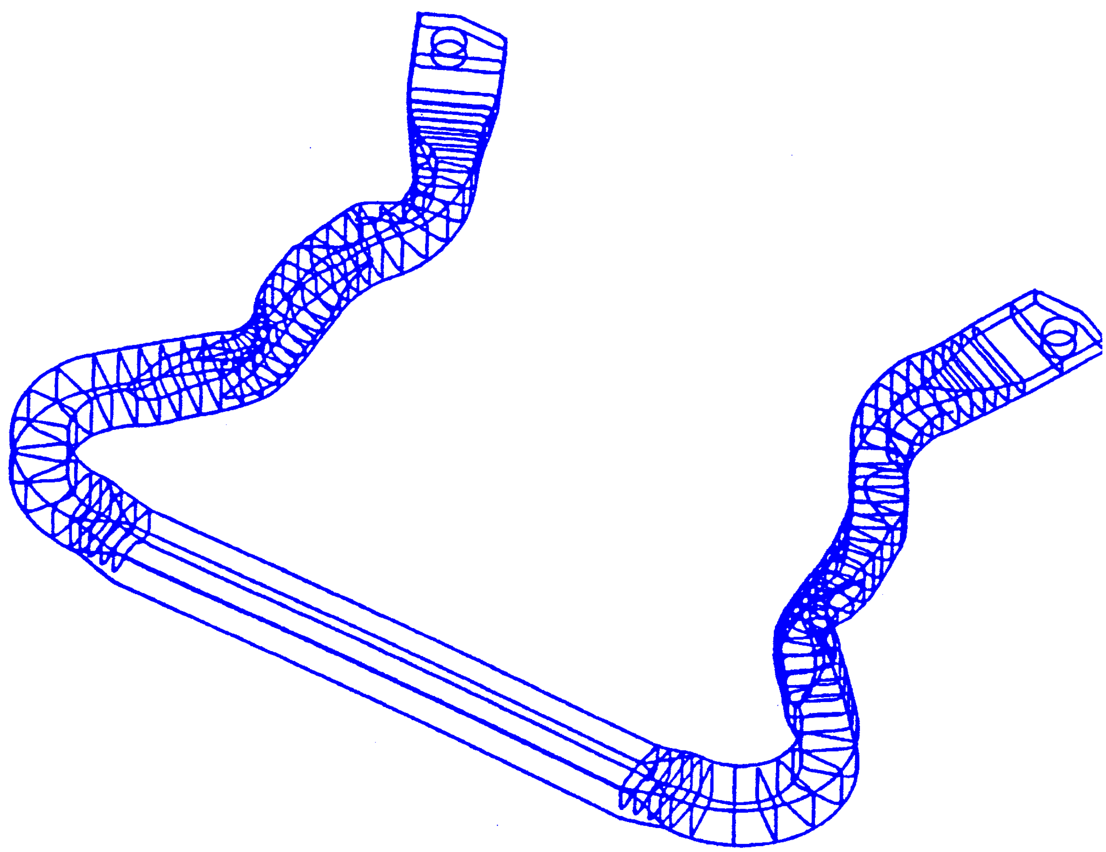
Examples of production low pressure hydroformed structures are:

1. Instrument panel support beams, 600,000-700,000 units per year for a single plant line.
2. Front suspension cradles, 350,000-450,000 units per year.
3. Radiator surround sub-assemblies, 300,000-400,000 units per year.

Part count has typically been cut in half for these structures. The radiator surround is less than 1.5 mm (0.060 in.) thick, is made out of cold rolled Galvanneal steel and is processed through the body ELPO tank. Suspension cradles are being made out of both mild steels and HSLA steels with yield strengths up to 310 MPa (45 ksi) minimum (See Figure 4.6.4.1-1).



(a) Suspension cradle as a six piece stamping assembly



(b) Suspension cradle as a single piece hydroformed tube

Figure 4.6.4.1-1 Suspension cradles

4.6.4.2 High Pressure Hydroforming

High pressure hydroforming may be required when either of the following is required:

- Additional expansion of the perimeter, up to 25 percent, with limited thickness reduction
- Wrinkle removal

If greater perimeter expansion or less thickness reduction is required, high pressure hydroforming combined with compression bulge forming, as illustrated in Figure 4.6.4.2-1, may be required.

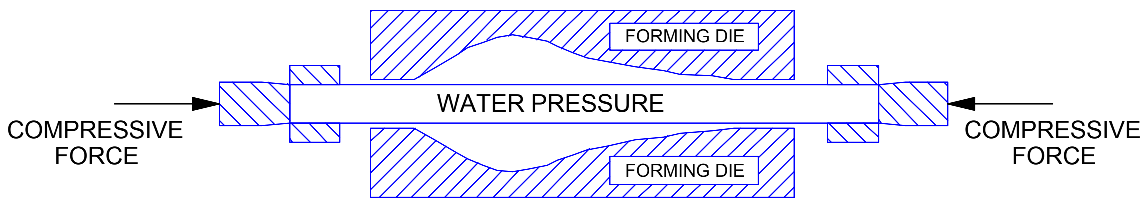


Figure 4.6.4.2-1 Typical compression bulge forming setup

High pressure hydroforming is arbitrarily defined as an expansion process using fluid pressure greater than 83 MPa (12,000 psi). Typical high forming pressures are in the range of 103 to 276 MPa (15,000 to 40,000 psi), with some options as high as 827 MPa (120,000 psi). High pressure hydroforming cycle times are longer than low pressure because;

- Presses are larger
- Tooling is more complex
- Inter-stage annealing has been used, but should be avoided in low carbon steels.

Bulge forming near the end of a tube, over a fairly straight section, can expand an AKDQ steel tube by more than fifty percent. In general, bulge formed cross sections seem to require larger minimum radii than do pure hydroformed sections.

Examples of production or prototyped high pressure hydroformed tubular structures are:

1. Frame front rails.
2. Rear suspension sub-frame members.
3. Steering column energy absorption bellows.
4. D-pillar for a low volume station wagon.

4.6.5 SIMULTANEOUS PROCESSING

In addition to reshaping the section of the tubular structure, holes can be punched using the fluid as a backup anvil, as illustrated in Figure 4.6.5-1. A variety of shapes, including round, square, oval and D-shaped, can be punched. The process presents two potential problems.

1. If slugs are removed from the holes, they must be removed in a way that does not allow them to fall back into the die. In some cases they can be retained in the tube and not interfere with part function or subsequent processing.
2. The holes tend to elongate in the direction of greatest strain, which may present a problem when cage nuts are employed.

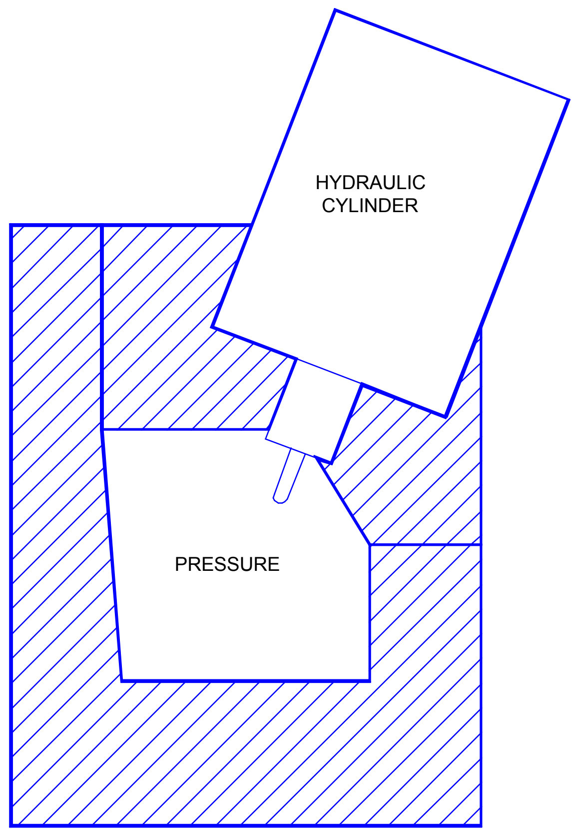


Figure 4.6.5-1 Piercing operation using fluid pressure for a back-up anvil

The hole size and location tolerances are comparable with those achieved by traditional machining and piercing operations.

Holes are typically pierced inward into the tube. If no extrusion is necessary, holes can be clean pierced. There will typically be a depression around the hole, but it does not generally cause problems for inserts. Extruded holes are also pierced to receive thread-forming fasteners. For example, pierced and extruded holes are being used to secure components such as fender assemblies, intercooler mounting brackets, transmission coolers, air intake filters and some structural components to radiator closures.

Holes in rolled corners can be pierced in the hydroforming die, and they remain nearly circular. The holes can be used to receive self tapping or thread forming screws to attach cosmetic panels or brackets. A plan for in-plant or field service repairs of these threaded holes will be required.

4.6.6 POST-HYDROFORMING PROCESSING

Pierced holes may be spin or flow drilled to open up the holes or to provide increased surface area for threads of structural fasteners. The process employs a high speed spinning tool to push the steel, rather than remove it. Drilling is typically used to improve the roundness of holes or to provide more accurate gaging locators.

Depending on the required complexity, tube ends can be removed by processes such as shearing, sawing and plasma cutting. Mandrels can be inserted a limited distance into the tube ends to permit resizing or reshaping. ELPO treatment of zinc alloy pre-coated steel, within limits, has been successful.

4.6.7 SUMMARY OF ADVANTAGES AND DISADVANTAGES

Hydroforming tubing provides the potential for the following advantages compared with alternative stamped and welded structures:

- Reduced tooling costs
- Part integration
- Integration of piercing and punching operations
- Elimination of pinch weld flanges
- Less or negligible die wear
- Potential improvements in dimensional repeatability

The dimensional repeatability of hydroforming versus alternate processes is shown in Table 4.6.7-1. The numbers are unitless based on hydroforming at 1.0.

Table 4.6.7-1 Dimensional repeatability of hydroforming versus alternate processes

Process	Stamped and Welded	Swept or Bent with Partial Yielding	Swept or Bent with Full Yielding	Swept or Bent plus Hydroformed
Relative Dimensional Variation	2.0.-3.0	2.0-2.5	1.5	1.0

Hydroforming may incur disadvantages or limitations compared with stamping and welding, such as:

- Difficulty of incorporating internal brackets
- Limits on perimeter length variation
- Relatively long cycle times
- Post processing operations for end treatments
- May require single sided spot welding, laser welding or MIG welding to attach bracketry
- May require special presses
- Incomplete ELPO treatment

The process appears to be neutral relative to mass reduction. However, in locations were high mass percentages of weld flanges might occur, and the flanges are not needed to mount other parts, some mass savings may be realized.

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