

Manufacturing Tubes For Hydroforming Applications

By F.J. Rípodas Agudo, Aceralia Tubes (Aceralia Transformados), Arcelor Group
& Professor of Manufacturing Technologies, Universidad Pública de Navarra, Spain

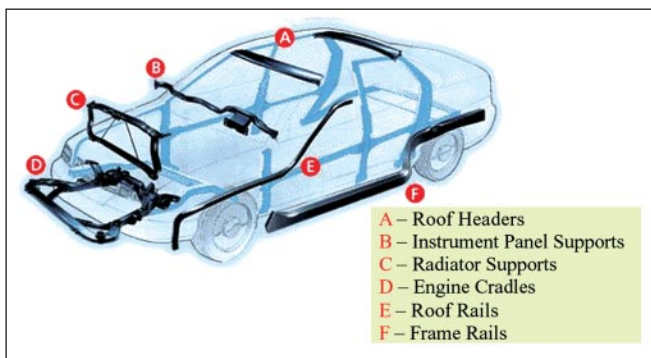
Introduction

The automotive industry is involved in a continuous process to minimize cost, but always taking into account the optimisation of its products concerning weight, strength characteristics and rigidity. The metal processing industry is working in this way in research and development for alternative materials and production processes.

The siderurgic industry has been involved in projects like ULSAB (Ultra Light Steel Auto Body), ULSAC (Ultra Light Steel Auto Closure) and others with these concepts. The results have demonstrated that by using steel as the material of choice – in conjunction with the utilization of advanced manufacturing processes – pieces can be produced that achieve a mass reduction, while increasing structural performances, and at no cost penalty. To compound this benefit, steel is the most recyclable material in the world. Hydroforming technology has therefore been called to offer an interesting technical and economic potential.

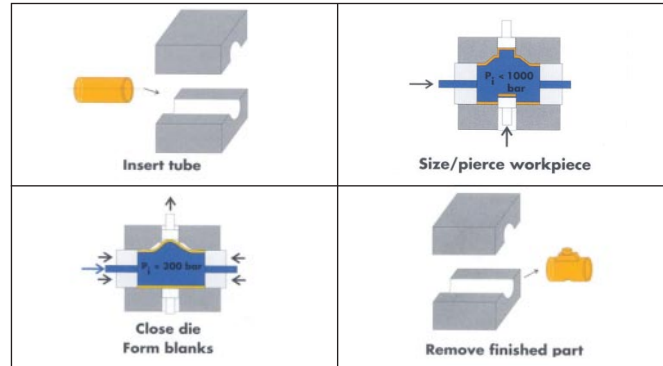
The Tubular Hydroforming Technique

Tubular hydroforming is achieving increasing acceptance in the automotive industry for making a wide variety of components. Current applications include suspension frame, body structure, power-train components and exhaust pipes. The major advantages of tubular hydroforming that have initiated these applications are cost reduction and weight savings, improved dimensional stability, improved integrity and increased strength and stiffness of the components.



Depending on the part design, pre-bending and pre-forming operations could be essential before the start of the tubular hydroforming process. In the tubular hydroforming process, a tube is first placed in the closed cavity of a forming die. Once the ends of the tube are sealed, the tube is filled and pressurized with hydraulic fluid. The internal pressure forces lead the tube to form into the shape of the tool cavity.

Most hydroforming processes also use axial force-feeding at the tube ends to feed material into the tool during forming. With the application of axial force-feeding, higher limits at the end of the part can be achieved.



Source: Krupp Hoesch Automotive

Hydroforming provides several advantages versus traditional stamped and welded structures, including:

- Reduced mass
- Reduced tooling costs
- Part integration and reduced part costs
- Integration of piercing and/or punching operations
- Elimination of pinch weld flange
- Improvements to dimensional repeatability

When used with high strength steels hydroforming is able to produce structurally superior parts with thinner sections at a reduced mass.

Hydroformed Tubes in ULSAB and ULSAC Program

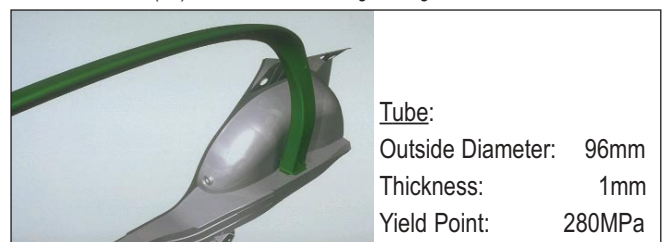
Tubular hydroforming was used in the ULSAB and ULSAC programs to improve structural integrity, reduce costs and achieve mass reduction.

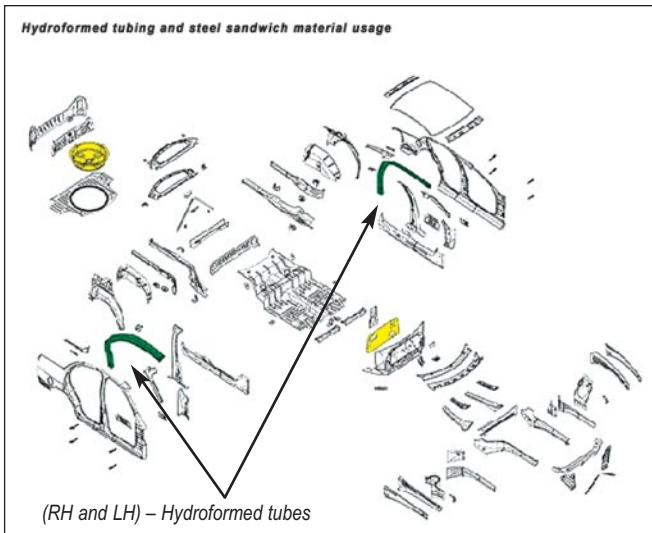
In the ULSAB Project

Tubular hydroforming and its cold working effect produces high dimensional stability and increases effective yield strength in any component. The part making process incorporates four steps:

- Making the tube
- Bending the tube
- Pre-forming the pre-bent tube
- Hydroforming the pre-formed tube into the final component shape

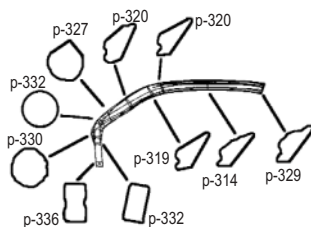
Rail side roof (LH) - Source: Porsche Engineering Services, ULSAB Consortium





❶ Rail side roof (RH and LH) - Hydroformed tubes
Source: Porsche Engineering Services, ULSAB Consortium

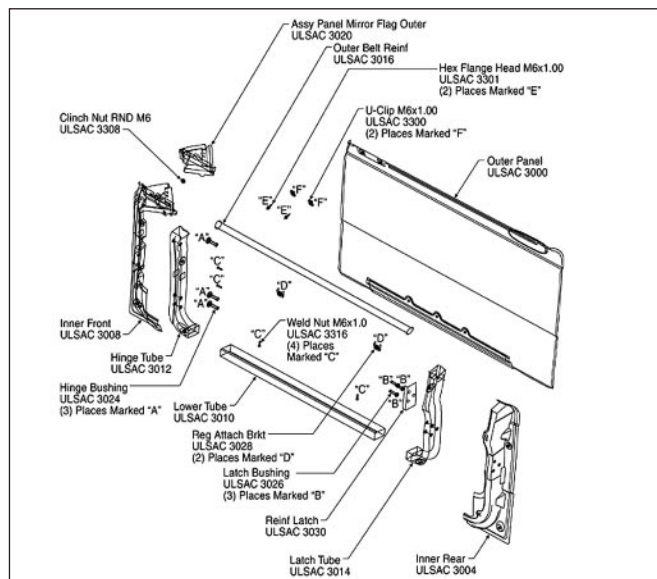
ULSAB's hydroformed side roof rail provides an essential load path for structural performance and crash energy management from the top of the 'A' pillar along the roof, into the 'B' and 'C' pillars and into the rear of the structure.



The hydroformed side roof rail reduces the total number of parts and maximizes section size, allowing for both mass and cost savings. The raw material for the side roof rail is a welded, high strength steel tube of thickness 1mm and outside diameter of 96mm. The yield strength is 280MPa.

In the ULSAC Project

In ULSAC, hydroforming is used to produce the latch and hinge tubes, adding stability to the door structure and allowing for integration of additional functions, such as the hinge attachment, latch attachment, and bushings.



❶ Design of the ULSAC door structure
Source: Porsche Engineering Services, Inc. ULSAC Consortium

Although both the hinge and latch tubes were manufactured with similar hydroforming process steps, the latch tube's smaller wall thickness and three-dimensional curves – made it a more complicated part to manufacture.

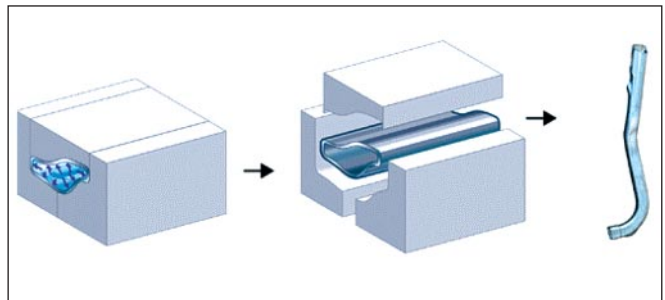
The part making process for latch tubes incorporates four steps:

Tube Manufacturing – The latch tube is made of 280MPa yield-strength high strength steel, using typical welding processes, such as high frequency and laser welding.

Pre-bending – Due to the three-dimensional curves of the latch tube, the straight tube must be pre-bent. A conventional mandrel-bending machine was used for this step.

Pre-forming – Pre-forming is necessary to achieve proper initial start geometry that fits into the hydroforming tool.

Hydroforming – The pre-formed tube is placed in the closed cavity of a forming die. Once the ends of the tube are sealed, the tube is filled and pressurized with a hydraulic fluid (1,500 bar for the latch tube), forcing the tube into the shape of the tool cavity. Axial force at the tube ends feeds material into the cavity during forming, enabling formation of complicated shapes.



❶ Source: Porsche Engineering Services, Inc. ULSAC Consortium

Requirements – Tubes for Hydroforming

Front Door Hinge Tube/Latch Tube:

Quality

Feature: Precision steel tube according to following specifications
Material: Zinc coated on both sides
Yield Strength: = 280 MPa on finished parts
Total Elongation: = 30 per cent (longitudinal and transverse)
Uniform Elongation: = 18 per cent

Dimensions and Tolerances

Outside Diameter: 48 mm +0.10/-0.00mm
Wall Thickness: Hinge Tube: 1.2mm +0.00/-0.05mm
Latch Tube: 1.0mm +0.00/-0.05mm
Gage includes coating thickness
Coating may be EG (Zinc only) or hot dip (Zn or FeZn)
The coating must be 65 gram/m² maximum (0.009mm)

Total Tube Length: 1350mm

Cutting of Tube Free of burr
Ends: No ovalizations or cave-in
No chamfers
Rectangular to longitudinal axis ±0.5°

Appearances of Tube

Surface: Free of mechanical damage, splatters, etc.
No collapsed areas (no indents, bulges, etc.)
Free of impurities (swarf, weld chips, etc.)

Welding Requirements

Welding Process: Laser or EB-welding or HF-welding

Weld Seam Area: Outside of tube: Undercut 0.00mm, no expansion
 Inside of tube: Undercut <0.15mm, no expansion
 No mismatch of edges
 Free of any porosity
 Strength similar to base material
 Sufficient overall roundness of tube

Material Selection

The material selection was done in material group meetings, attended by expert representatives of the Consortium member companies. The material types and grades selected for manufacture of the test door structure were according to the design material thickness specification.

No.	Part Name	Materials Spec.			Blanks
		Min. Yield Strength	Thick (mm)	Material Type Selected	
3012	Front Door Hinge Tube RH (48mm outer diameter)	280	1.2	HSST280	48 dia x 1000
3014	Front Door Latch Tube RH (48mm outer diameter)	280	1.0	Isotropic 280	48 dia x 1000

Part No.	Delivered Material Properties	Material Thickness (mm)	Yield Strength (0.2% offset) (Mpa)	Tensile Strength (Mpa)	Elongation A80 (%)	r-value	n-value	Coating
3012	HSS280	1.20	357	394	37	N/A	0.08	GI
3014	Isotr.280	0.97	273	361	41	N/A	0.19	EG

GI = Hot-Dip Galvanized

EG = Electro Galvanized

Chemical Composition (%)										
Part No.	Material	Thickness (mm)	C	Mn	P	S	Si	Cu	Sn	Ni
3012	HSS280	1.20	0.007	0.521	0.073	0.006	0.082	0.009	0.002	0.019
3014	Isotr.280	0.97	0.040	0.195	0.01	0.007	0.013	0.018	0.004	0.034
Part No.	Material	Thickness (mm)	Cr	Mn	Al	V	Nb	Zr	Ti	Co
3012	HSS280	1.20	0.019	0.004	0.040	0.003	0.005	NA	0.064	0.004
3014	Isotr.280	0.97	0.021	0.005	0.052	0.002	0.003	NA	0.027	0.007

Tube Manufacturing Processes

The tubes can be manufactured in different ways. From the first tubes manufactured by forging, to the actual systems, there is an historical evolution of the technologies:

Different Processes of Forming (Discontinuous and Continuous):

- Forging
- Extrusion
- Roll-Forming
- Folding

Processes of Junction:

- Butt-Welded
- Electric-Welded (resistance, induction: HF, MIG, TIG)
- Forging pressure
- Laser

The manufacturing tube processes for hydroforming applications must match the quality exigencies of this industry and, yet, have a cost as low as possible.

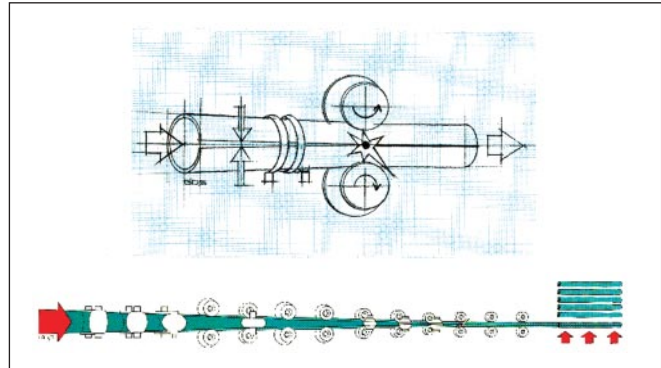
The Most Common Forming and Welding Processes are:

- Continuous roll-forming, HF or laser welded tubes
- Discontinuous forming laser welded tubes
- Cold-drawing tubes from a continuous roll forming HF welded tube

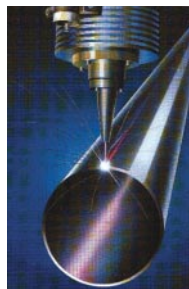
Continuous Rollforming Process

A steel strip is continuously roll formed into a tube shape and the longitudinal gap is continuously welded by applying high frequency welding process. The welding process is a result of inductive heating and compressing the edges of steel strip without supplementary material.

The following sizing leads to exact tolerances of the tube for the hydroforming process. The external bead of the welded area is always removed, and the internal only when it is necessary.



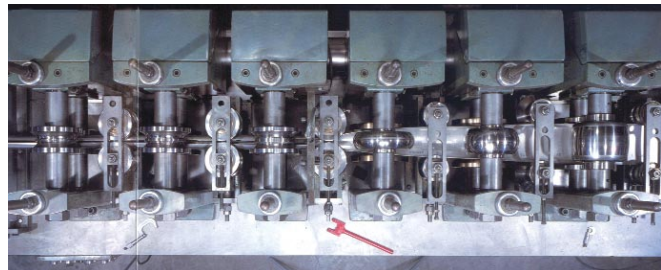
Source: V.W. Werke Vincenz Widerholt GmbH



The second process is the use of laser welding for joining. Laser-welding eliminates the bead.

Compared to the high frequency welding, there is a much smaller heat-affected and decoated welded zone (if the raw material is coated).

W.F. Oppermann (VDI) Rohrwerktechnik



Source: Roll-Kraft

Characteristics of the Continuous Roll Formed Tubes:

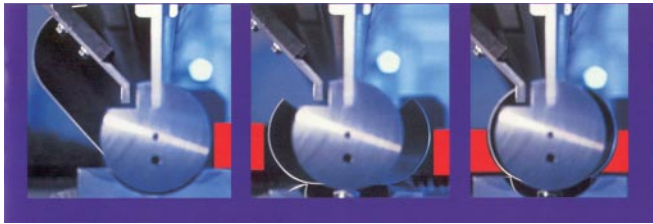
- High productivity (HF welded systems); Low cost
- Maximum D/t ratio about 80
- Cylindrical cross section
- HF welded system (production speed 50÷180m/min.) removes the external and internal bead
- Laser welded system (production speed: up to 15–18m/min.)

Discontinuous Forming Process

A metal sheet is folded and bended into a tube shape piece by piece. Then, the longitudinal gap is welded by application of a laser welding process. Blanks can be produced in a tailored way, in conical form to obtain the subsequent tube.

The Characteristics of Discontinuous Forming and Laser Welding Tubes:

- High D/t ratio (200 ÷ 250)
- Tailored tubes
- Cylindrical and conical cross sections
- More formability (due to forming process)
- Higher formability of the laser-weld area



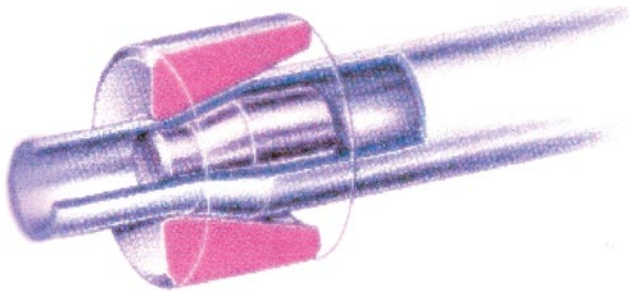
Source: Soudronic

Cold Drawing Tubes

A HF roll formed tube or seamless tube is drawn into a tube. This tube has been reduced to a new final diameter and thickness. The process is made by means of both an external and an internal mandrel.

The original tube goes through, at least, these processes:

- Thermal treatment – normalizing
- Straightening and pointing
- Chemical processes
- Cold drawing
- Final straightening
- Cutting
- Non destructive control
- Dimensional control



Cold drawing process
Source: Aceralia Transformados

The Characteristics of the Cold Drawing Tubes:

- Very tight tolerances (both external and internal diameter)
- Surface appearance
- Low superficial roughness

Today, longitudinally HF welded tubes constitute the most cost-effective alternative both to the laser welded tubes and to the cold drawn tubes. Optimized manufacturing methods led to the fact that it is possible to manufacture tailored tubes. The use of tailored tubes is the consequent development of welded profiles, which unlike standard tubes are capable of creating suitable hydroforming conditions. Every kind of these tubes can be supplied with final conditions like stress relieving, annealing or normalizing.

Requirements on Tubular Products

Hydroforming is defined as a process of manufacturing complex hollow components, in most cases using circular tubes as source material.

It is vital to carefully check and ensure that the tube to be hydroformed retains the highest amount of formability and residual elongation factors, crucial to the effective use of this technology.

Hydroformed parts distinguish themselves by a complex cross section geometry, which varies considerably above the longitudinal axis tube and in many cases even show punches, and so on.

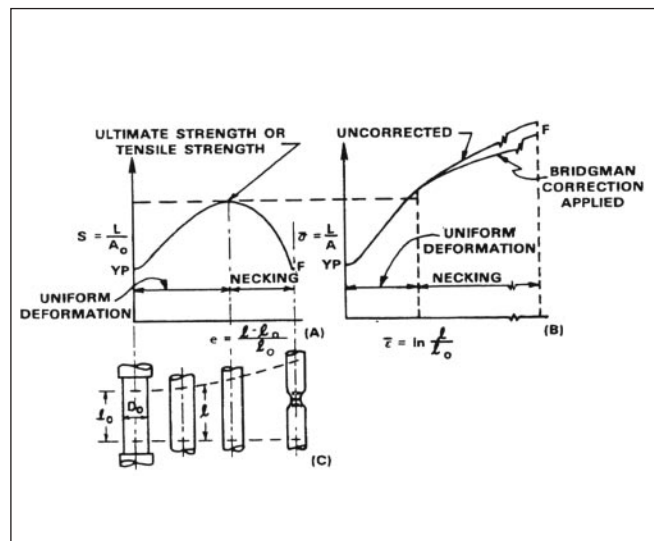
The rest of the main requirements, in geometry and appearance, placed on tubular products can be summarized as:

- Tube outer diameter
- Wall thickness
- Length (in many cases, it depends on the further processing system)
- No scratches and grooves to avoid fatigue strength
- Clean and chipless
- Cut rectangular to axis
- Deburred tube ends
- Rustfree
- Homogeneous formability (the longitudinal seam welding should have a very slight influence)
- Circular (or shape-desired) cross section geometry (continuous geometry)

Furthermore, there are some additional requirements on the material that is used to form the tube:

- Tensile strength
- Yield point (0.2 per cent)
- Flow curves
- Uniform elongation
- Total elongation (longitudinal and transversal)
- n, r values
- Forming limit diagram (FLD)

The deformation capability of a tube is restricted by *buckling*, *wrinkling* and *bursting*.



Tubes Manufactured for Hydroforming Applications – Examples

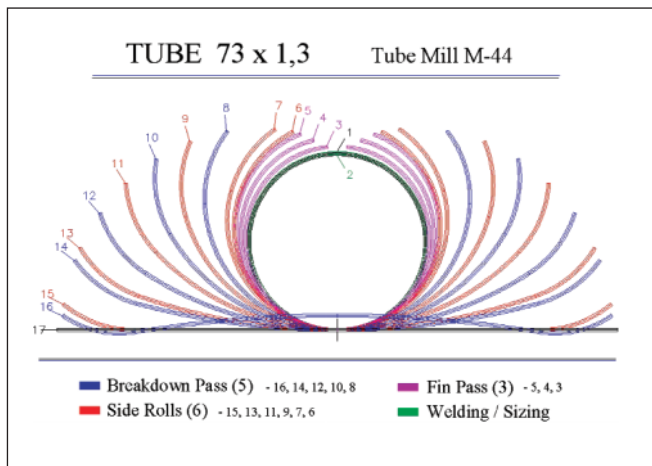
Different tubes are being manufactured at the moment, for several hydroforming applications.

We will analyse two different tubes that have been designed according to the concepts previously described.

TUBE 73 X 1,3

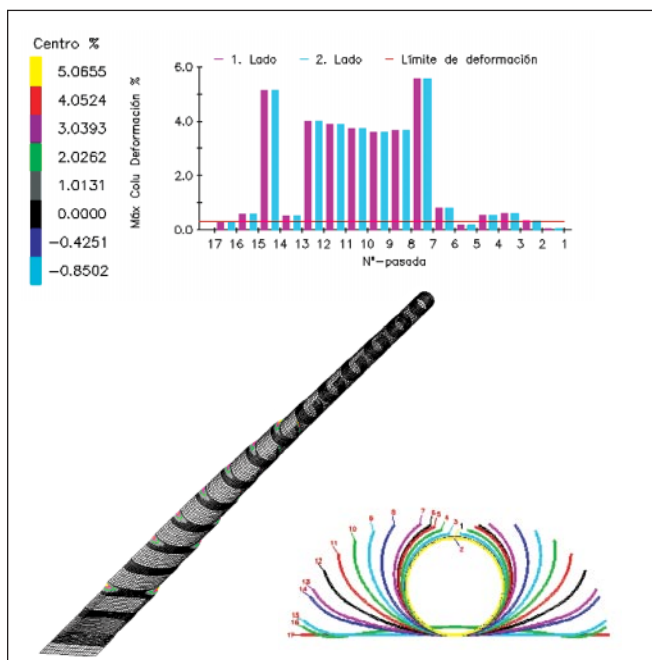
This tube (known as crossmember) is intended to work as an instrument panel support after being reprocessed using the hydroforming technique. The raw material used is cold rolled DC03 (EN 10130).

The flower design for this tube is as follows:



Flower for tube mill M-4

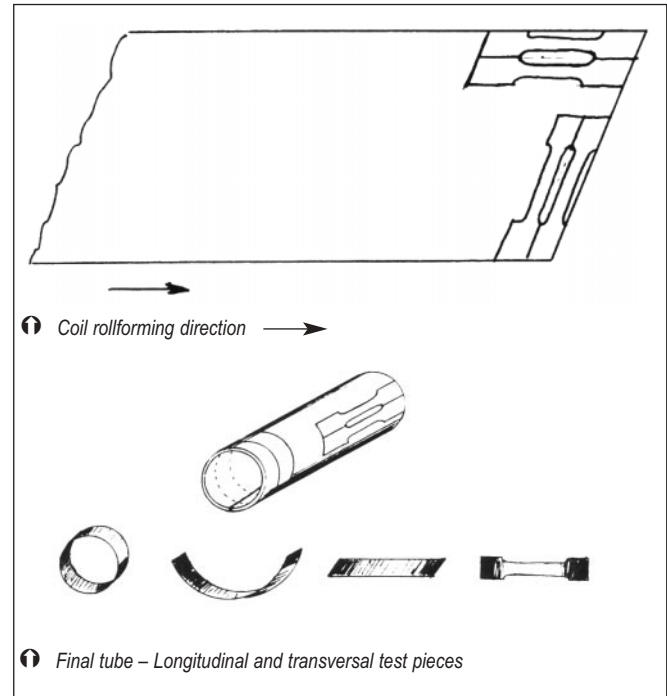
As stated before, the process of manufacturing must be carefully studied. Thus, specific software is used to calculate the elongation/compression and strains of the material through the forming process, in order to get the optimal design.



In order to complement this information, a set of technical data about this tube follows:

Chemical composition of the raw material (coil)

% C	% Mn	% P	% S	% Si	% Al
< 0,08	< 0,4	< 0,025	< 0,025	< 0,03	0,020 – 0,040



Mechanical characteristics of the coil

EN 10002-1	Test piece – Proportional (L ₀ =5·d)		Test piece – Non-proportional (L ₀ =80)	
	Longitudinal	Transversal	Longitudinal	Transversal
R _{p0,2} (N/mm ²)	204	208	202	194
R _m (N/mm ²)	317	321	316	316
A _{5,d} / A ₈₀ (%)	57,6	56,2	36,7	38,9
A _g (%)	-	-	19,6	20,0

Mechanical characteristics of the tube

EN 10002-1	Test piece – Proportional (L ₀ =5·d)		Test piece – Non-proportional (L ₀ =80)	
	Longitudinal	Transversal	Longitudinal	Transversal
R _{p0,2} (N/mm ²)	228	222	224	226
R _m (N/mm ²)	323	320	320	322
A _{5,d} / A ₈₀ (%)	55,2	57,9	38,0	35,4
A _g (%)	-	-	20,1	19,3

Tube 60 X 2

This tube (known as subframe) is intended to work as an engine cradle after being reprocessed using the hydroforming technique.

The raw material used is a DD13 (EN 10111) with a chemical composition similar to that of the crossmember.

There is a possibility to manufacture this tube in different mills, each one of them requires its own flower and tool design. The software mentioned above can handle these possibilities with ease.

Mechanical characteristics of the coil

EN 10002-1	Test piece – Proportional ($L_0=5 \cdot d$)	
	Longitudinal	Transversal
$R_{p\ 0,2}$ (N/mm ²)	215	227
R_m (N/mm ²)	319	316
A_{5-d} (%)	49,2	49,6
A_g (%)	20,4	20,5

Mechanical characteristics of the tube

EN 10002-1	Test piece – Proportional ($L_0=5 \cdot d$)	
	Longitudinal	Transversal
$R_{p\ 0,2}$ (N/mm ²)	252	242
R_m (N/mm ²)	327	323
A_{5-d} (%)	49,9	50,6
A_g (%)	19,8	19,9

The forming processes for both tubes are soft enough not to significantly change the mechanical properties from the coil to the final tube.

🔗 Subframe from tube 60x2



🔗 Crossmember from tube 73x1,30
Source: Aceralia Transformados, GESTAMP HB Hidroacero



Conclusions

Longitudinally welded steel tubes meet the high requirements placed on tubular products during hydroforming.

Adapting materials, forming processes and welding methods, the manufacturing of tubes for hydroformed parts is optimised, and becomes a really cost-effective process with high standards in quality and complexity of the products than can be manufactured.

Besides the experiences on tube manufacturing gained from the decades of activity of Aceralia Tubes, additional sources of information have been used to complete this article.

References and Bibliography

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Porsche Engineering Services, Inc., ULSAB electronic report 1.0, 1998
Porsche Engineering Services, Inc., ULSAB final report
Porsche Engineering Services, Inc., ULSAC overview report, May 2001

Additional Texts on Hydroforming:

Leitloff, F-U, Innenhochdruckumformen mit dem Schäfer-ASE-Verfahren, Stahl (1995) 5.

Malle, K., Aufweiten – Stauchen – Expandieren, VDI Journal 137 (1995) 9.

Suwat Jirathearanat the Ohio State University,
Simulations in Tube Hydroforming: Optimization of Loading Paths
http://nsmwww.eng.ohio-state.edu/THF_AMERI-PAM02_110602.pdf

Additional Information on ULSAB and ULSAC Projects:

<http://www.worldautosteel.org/>

<http://www.ulsab.org>

<http://www.ulsac.org>

Other Resources

<http://www.hydroforming.net/>

<http://www.tubehydroforming.com/>

<http://nsmwww.eng.ohio-state.edu/html/t-reports.html>

<http://www.steel.org/autosteel/index.htm>

Aceralia Transformados SA
Barrio Zalain Zoko, Apartado 36
E-31780, Bera – Navarra, Spain
Fax: +34 948 628 414
E-mail: fripodasa@aceralia.es