7. Material & Processes

7. Material and Processes

7.1. Material Selection

7.1.1. Material Selection Process

Based on ULSAB Phase 1 results, the body structure was redesigned in Phase 2 as described in earlier chapters of this report. With respect to the new influences, such as crash requirements and styling, new calculations had to be made. The calculations concerning static behavior gave us a first indication of the sheet metal thickness needed. This is because performance is mainly related to sheet metal thickness and the design itself, and not to the strength of the material, because the E-modulus is very similar for all steel types. After the initial material selection, the first loop of crash calculations was performed. As a result, the material grades and/or the sheet metal thicknesses had to be adjusted.

Several iterations of the "Material Selection Process" (Figure 7.1.1-1) lead us to the optimal strength/thickness level for each part. This procedure included a manufacturing feasibility check with our selected part suppliers. For the most critical parts, a forming simulation was performed simultaneously by the steel suppliers. The results of these simultaneous engineering processes have been important factors in successfully meeting the challenges of developing manufacturable parts. Different criteria during the material selection process such as formability, weldability, spring-back behavior, and static and dynamic properties were always taken into consideration.

Always having "Production Intent" in mind, the focus was on production-ready materials, not on materials that are available only in laboratory scale. General material specifications and the definition of the different material grades are described in section 7.2 of this chapter.

Material Selection Process

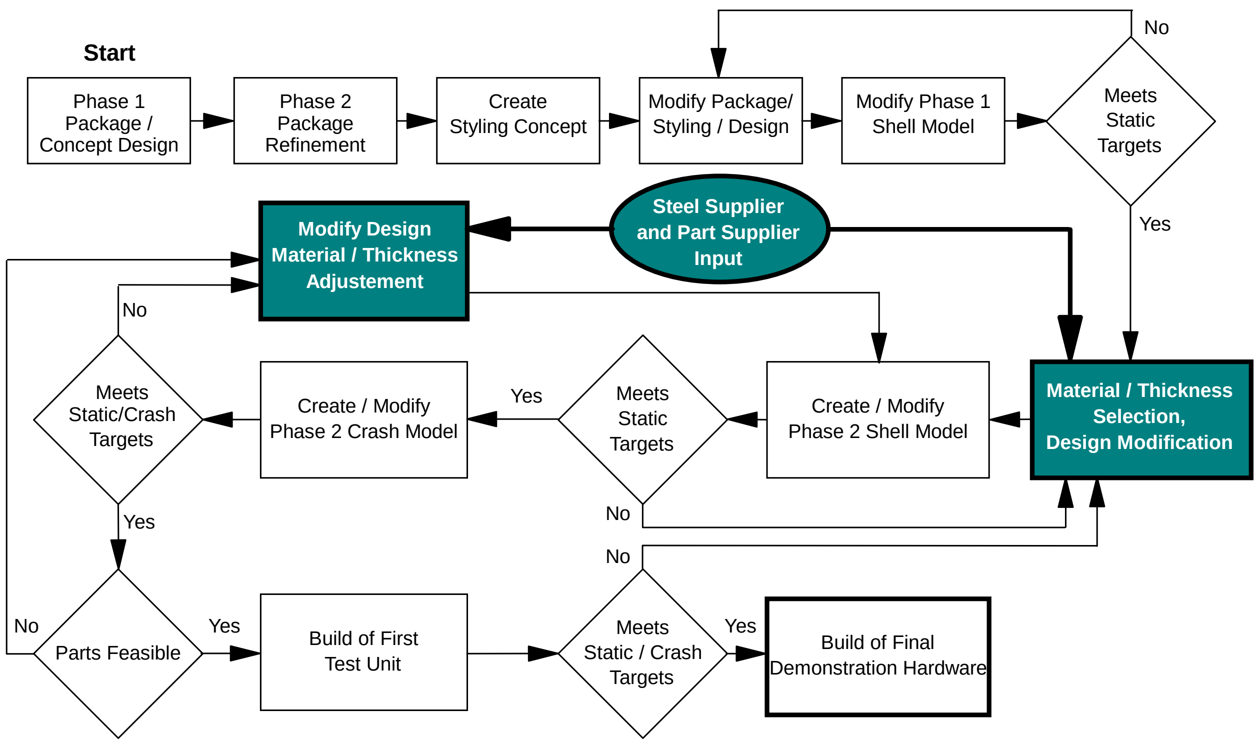


Figure 7.1.1-1

7.1.2. Definition of Strength Levels

In order to use the minimum variety of materials, every "master item" was defined by thickness and strength. The same master item could be used for different parts, as long as thickness and strength requirements were met, and the part suppliers and forming experts had no concerns. The definition of strength levels as used in ULSAB Phase 2 is shown next in the "ULSAB High Strength Steel Definition."

ULSAB High Strength Steel Definition

The ULSAB program designates steel grades by specified minimum yield strength in the part. The following steel grades are utilized in the ULSAB design:

Minimum Yield Strength	Category
140 MPa	Mild Steel
210 MPa	High Strength Steel
280 MPa	High Strength Steel
350 MPa	High Strength Steel
420 MPa	High Strength Steel
Greater than 550 MPa	Ultra High Strength Steel

This definition was chosen in order to standardize the steel grade definitions for the ULSAB Consortium member companies since many countries are involved and the standards are not the same around the world. This has to be seen together with the goal that the ULSAB body structure could be built in every region of the world where steel is available. This is also the reason that the suppliers of the material for the DHs are kept anonymous within the ULSAB program.

The most suitable material for each part application was chosen with the assistance of experts from the steel suppliers. This process was especially important for the ultra high strength steel because of its more critical forming behavior. Different materials such as dual phase (DP) steels are included in this group of ultra high strength material parts.

There are several ways to achieve the 280 MPa yield strength level according to the above definition. This could be done by using microalloyed high strength steel, bake hardening or even dual phase steel. However it is achieved, the minimum yield strength for the finished part has to be 280 MPa in each area of the part. Other material qualities and material types could achieve the same or similar results; therefore, several factors affected material selection including material performance and availability.

7.1.3. Supplier Selection

Once the “master items” were defined, the material supplier selection was made. This was done in material group meetings attended by all steel supplier experts and the design and manufacturing team of PES. For every part of the ULSAB, a minimum of two material sources were selected.

The fact that different materials with the same yield strength level were available for each part (not only from different suppliers, but also in many cases different material types, such as microalloyed or dual phase) shows that most of the ULSAB parts could be made in multiple ways. No specially treated or designed material was necessary. Most of the material was taken from normal serial production at the steel mills.

In order to practice simultaneous engineering most efficiently, the material suppliers were selected by their close proximity to the part supplier’s location (press shop). If the material failed during the first try-outs it was easier to react with corrective steps such as circle grid analysis, material tests, or forming simulations.

Similar criteria were used in selecting the welding sources for the tailor welded blanks. In most cases two different companies could have provided the same welded sheet, each with slightly different material qualities. This again underscores that the ULSAB can be built with widely available material and part manufacturing technology.

7.2. Material Specifications

7.2.1. General Specifications

General specifications for the material used on the ULSAB only concerned thickness tolerances, coating requirements and coating tolerances. The specifications are as follows:

- Actual thickness of blanks must measure +0.00 mm/-0.02 mm of the specified thickness
- Coating may be electro-galvanized (Zn only) or hot dip (Zn or ZnFe)
- Coating thickness must be 65 gram/m^2 maximum (0.009 mm) per side with coating on both sides

Every delivered material had to be tested at the supplying source before it was shipped to the part manufacturer. A test report accompanied the material until the parts are finished. This is the basis for the Advanced Quality Planning (AQP) report that was performed by the ULSAB Consortium. The test results are also considered for welding parameter evaluation at the prototype shop.

7.2.2. Material Classes

7.2.2.1. Mild Steel Definition

Mild steel, which is described in Sec 7.1 Material Selection, is material with a yield strength level of 140 MPa. Mild steel can also be defined in terms of "Draw Quality," "Deep Draw Quality" or "Extra Deep Draw Quality." The material has no fixed minimum yield strength but does have a minimum elongation. Mild steels are the most common steels used in auto making today. This is because mild steel has forming and cost advantages compared to high strength steel. On the other hand, the ULSAB clearly shows that the amount of high strength and ultra high strength steel can be used up to more than 90% or more without any cost penalty.

7.2.2.2. High Strength Steel Definition

The steel industry has developed various high strength steel qualities. In the ULSAB Phase 2 program the strength levels of 210, 280, 350 and 420 MPa were defined as high strength steel. The values are related to the strength of the finished parts as assumed in the FEA model. This includes additional strengthening as a result of the bake-hardening process also.

High strength steels were used where the design required certain crash and strength characteristics. Within the range of this material group, different strengthening mechanisms can contribute to the final result. The DHs used micro-alloyed steels, phosphor-alloyed steels, bake-hardening steels, isotropic steels, high-strength IF - steels and dual-phase steels, all in the range of the above-mentioned yield strength. This engineering report does not include a detailed description of alloying or other metallurgical processes that are used to produce those steel types.

7.2.2.3. Ultra High Strength Steel Definition

Ultra high strength steels are defined as steels with a yield strength of more than 550 MPa on the finished part. Parts made from these steels can provide additional strength for front and side impact. In the ULSAB structure, all crossmembers of the floor structure were designed in ultra high and high strength steel.

Today, there are different ways to achieve needed strength levels. This could be done for automotive sheet panels with dual phase (DP) steels, or with boron-alloyed types, which have to be hot formed. Within the ULSAB Phase 2, parts were made from DP steels. DP steels were feasible even on parts with a complex shape like the cross member dash. As of today, those types were also available in an appropriate thickness range, which is interesting for automotive applications, e.g. a thickness between 0.7 and 1.5 mm.

7.2.2.4. Sandwich Material Definition

The use of sandwich material has contributed to considerable mass savings on the ULSAB. The sandwich material is made with a thermoplastic (polypropylene) core, which has a thickness of about 0.65 mm. This core is "sandwiched" between two thin outer steel sheets with a thickness of about 0.14 mm each. The polypropylene core of this sandwich material acts as a spacer between the two outer sheets, keeping the outer surfaces away from the neutral axis when a bending load is applied (see fig. 7.2.2.4-1). The mentioned material (total thickness about 0.96 mm when coated) has a very similar behavior compared to a solid sheet of steel with a thickness of about 0.7 mm.

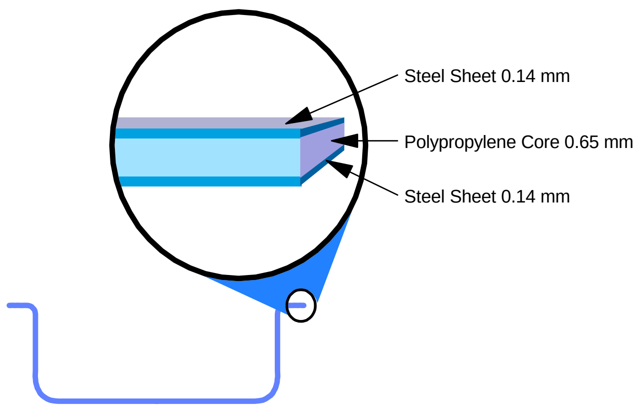


Figure 7.2.2.4-1 Sandwich Material

This sandwich material shares many of the same processing attributes with steel sheets, like deep drawing, shear cutting, bonding, etc. But, unfortunately, it cannot be welded. Even mechanical joining like riveting, clinching or screwing, can be a problem when the material has to go through the paint-baking oven. The core material is softened by the heat and flows away from the area where a pretension from a screw is applied. This may lead to a loss in joining strength.

Therefore, applications used in the ULSAB Phase 2 design were with parts made from sandwich material that did not go through the oven. The spare tire tub is designed as a prepainted module, preassembled with spare tire and tools. This module will be dropped into place and bonded to the structure during the final assembly of the vehicle. No additional heat has to be applied. Another application of sandwich material is the dash panel insert, which was bolted and bonded into the panel dash during final vehicle assembly.

Because there was no application similar to the spare tire tub in the past, an extensive forming simulation was performed on this part. Once the design was adjusted using the results of the simulation, there were no major concerns about the feasibility of the spare tire tub. After a small refinement of the best drawable radius, the parts were determined to be manufacturable with no problems.

Furthermore, a physical test with the spare tire tub was performed to check the fatigue behavior of this material for the application. Parts from the described sandwich material were made and compared to parts made from solid steel sheets of 0.7 mm thickness. A picture of the test installation is shown below in Fig. 7.2.2.4-2.

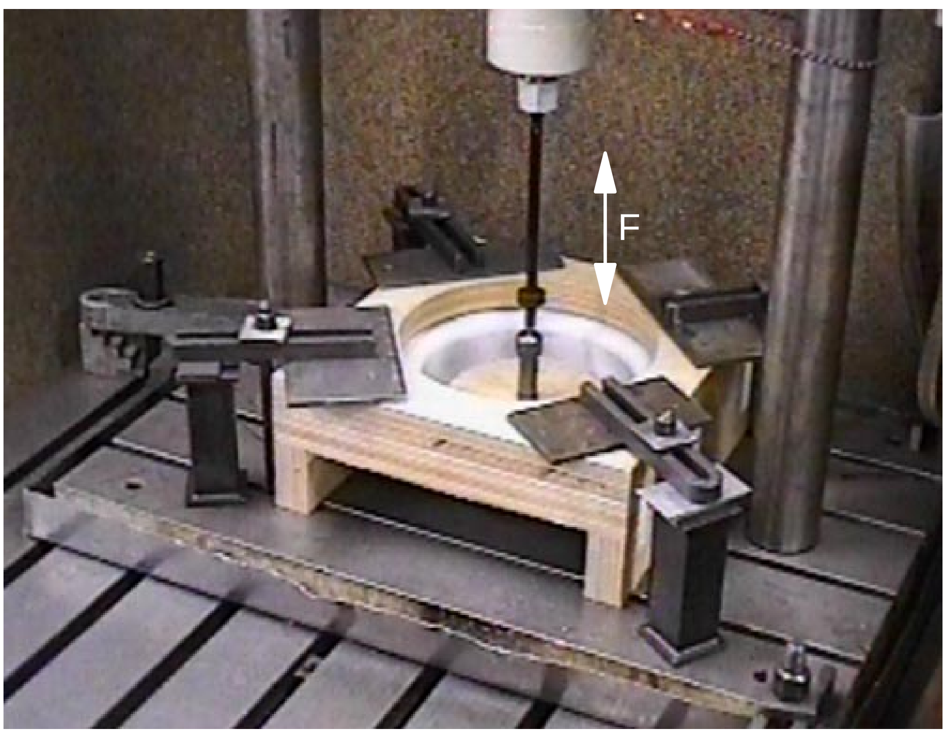


Figure 7.2.2.4-2 Test Installation

The load signal that was applied was taken from Porsche's proving ground and adjusted to the situation of the ULSAB. The test concluded there are no restrictions for the use of the sandwich material for the proposed application when it is compared to a conventional design using a 0.7 mm solid steel sheet.

The parts that were designed for the ULSAB could be made up to 50% lighter than those made of solid steel under similar dimensional and functional conditions. But, higher costs for the sandwich material have to be taken into consideration as compared to normal coated steel sheets.

7.2.3. Material Documentation

As mentioned earlier, every "Master Item" (material defined by thickness and strength) was accompanied by a test report, which includes all important strength properties, r- and n- values and a coating description. Those tests were performed by the supplying steel mills. All the supplied materials are documented at PES with their corresponding values, such as blank size, properties, coatings, material type etc. The "Master List" was also the base for the documentation of the welding parameters and the DH build itself.

When the parts were manufactured, the above-mentioned documentation was completed with additional information concerning press conditions for parts made at different locations. For those parts where a forming simulation and/or a circle grid analysis were performed, the documentation was extended with the results from these additional steps. These results are included in the earlier mentioned AQP report.

To ensure proper and comparable documentation, material samples from every part, that goes into the DH were collected by PES and sent to a central testing source. At this neutral location, every collected material was tested in the same way and documented again.

7.3. Tailor Welded Blanks

Introduction

Tailored blanking for vehicle body structures is a well known process with the first applications being done for mass production which started in 1985. Below listed are the main reasons for PES´s decision to use tailor welded blanks in a relatively large number compared to vehicles already on the market:

- Mass reduction due to the possibility of placing optimum steel thicknesses and grades where needed
- Elimination of reinforcements with appropriate material gage selection
- Simplified logistics due to the reduction of parts
- Investment cost reduction of dies, presses etc. due to fewer production steps
- Better corrosion protection by the elimination of overlapped joints
- Improved structural rigidity due to the smoother energy flow within the tailor welded blank parts
- Better fatigue and crash behavior compared to a conventional overlapped spot welded design solution

7.3.1. Selection of Welding Process

Laser welding and mash seam welding are the most common processes for the manufacturing of tailor welded blanks today. Induction and electron beam welding have a minor importance and they are still under development. All these processes have their advantages and disadvantages, related to the process and the machine itself.

Induction welding is a butt welding process. The necessary compressing of the two sheets creates a bulge with the consequence of an increase in thickness in the joined area. Those blanks could not be used in visible areas without an additional surface finishing process. A high accuracy during the movement of the sheets is important. The heating of the weld seam by induction / magnetic current over the total length leads to a larger heat affected zone when compared to laser welded blanks.

The non-vacuum electron beam welding process is similar to laser welding in the result of the weld seam geometry. This is due to the fact that it is a non-contact process as well. The beam is a mass beam and the kinetic energy of this beam is used for heating the material. The beam can be focused by a magnetic spool and the diameter can be adjusted easily. The advantage of this process compared to laser is the increased efficiency of about 90% compared to 10% when using laser. But a disadvantage is that the electron beam creates x - rays. This influences the machine design dramatically regarding total investment and material handling. Therefore this process is not used extensively up to now.

Mash seam welding needs a narrow overlapping of the sheets which have to be welded. The material in this area becomes doughy, not really fluid. During the welding process the current flows from one electrode to the other one and by resistance heating the sheet material becomes doughy. The electrode force then mashes the weld area and the sheets are joined together in this way. This light overlap and the joining process by force loaded electrodes results in a weld zone between 2.5 and 3.0 mm. The coating maybe is affected in this zone negatively. Furthermore, experience has shown that the surface of the weld zone, where little caves and pinchers occur due to the mash welding process, may not achieve the required corrosion resistance.

The laser welding process is used more and more widely. It is a non-contact welding process, and the heat is brought into the material by a coherent light with high energy density. In this way a very narrow weld zone can be achieved. There is almost no influence on the corrosion resistance when coated material is used. The main critical point on this process is without any doubt the need for very precisely prepared edges of the sheet. But this problem could be overcome by today's available precise cutting technologies or advanced fixing and clamping devices. One of the biggest advantages is the possibility of a non-linear weld line layout.

Different combinations of laser sources and clamping devices are on the market today. In many cases the sheets are moved relative to the fixed laser beam. This may lead to a reduction of the cycle time of the whole process.

Together with the fact that most of the newest installations for welding blanks are laser equipped devices, and the positive experience of PES, has lead to the decision to use laser welded tailored blanks on the ULSAB body structure exclusively. The blanks were produced at different locations using different equipment from the whole range of possible installations. The weld lines were controlled during the joining process to maintain the following features:

- width of the remaining gap
- mismatching of blank edges
- blank position
- seam geography (concavity, convexity)
- lack of penetration

All of these lead to the high quality of today's tailor welded blanks.

7.3.2. Weld Line Layout

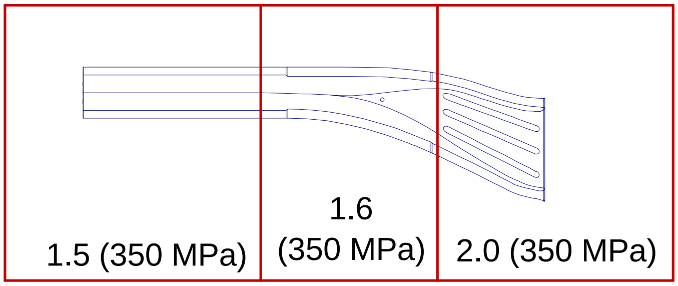
The weld line layout was mainly driven by the crash calculation results. Forming feasibility requirements also influenced it. On some of the most critical parts, e.g. the body side outer panel, a forming simulation was performed. Necessary changes from this simultaneous engineering process were incorporated in the weld line layout.

The following parts on the ULSAB body structure were designed as tailor welded blanks:

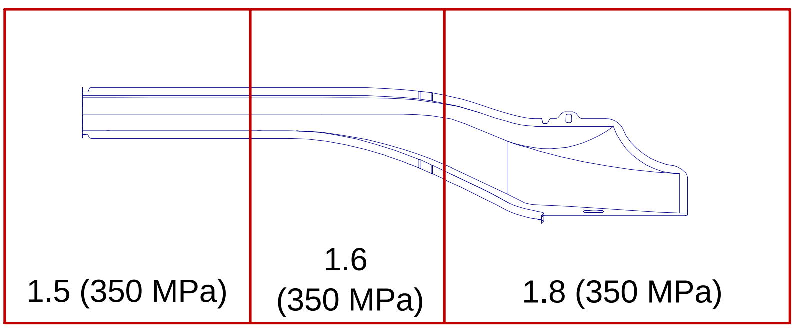
- Front Rail Outer
- Front Rail Inner
- Panel Rocker Inner
- Rear Rail Inner
- Rear Rail Outer
- Panel Body Side Outer
- Panel Wheelhouse Outer
- Panel Skirt

The weld line layout is shown in the following pages for each part.

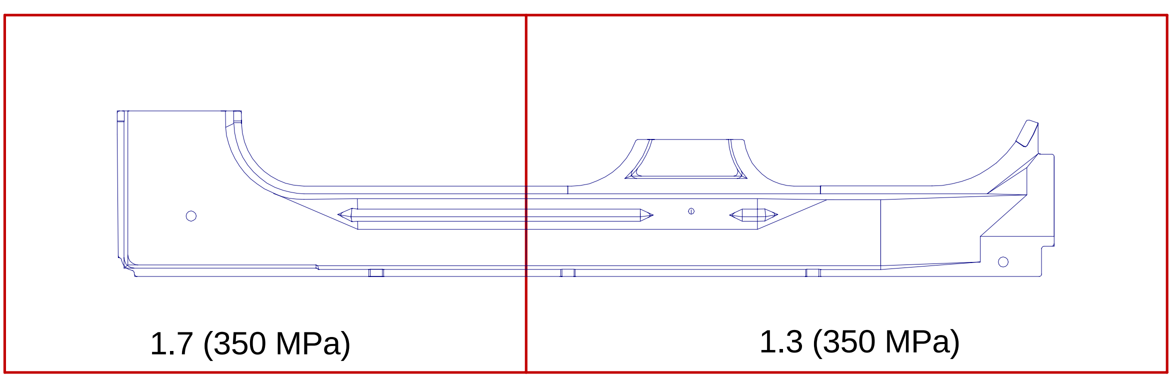
ULSAB 008 - Rail Front Outer



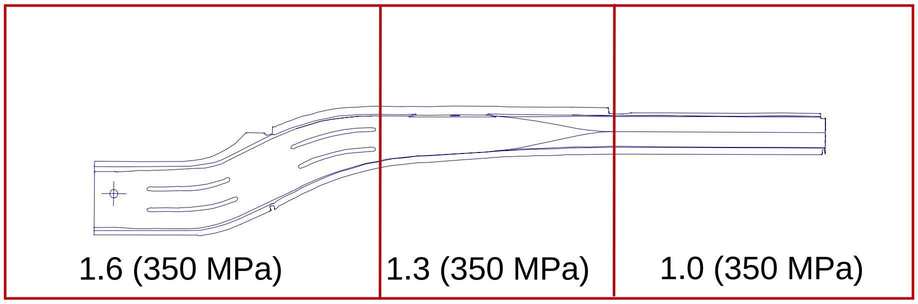
ULSAB 010 - Rail Front Inner



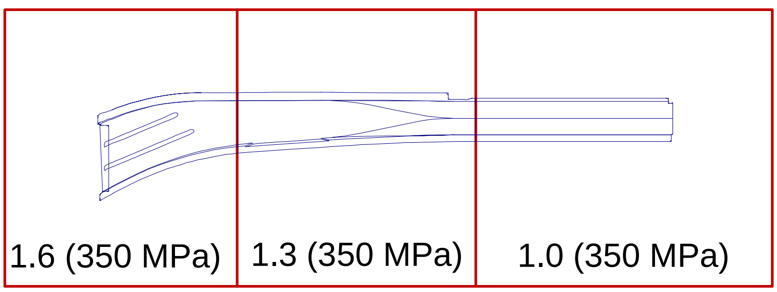
ULSAB 042 - Panel Rocker Inner



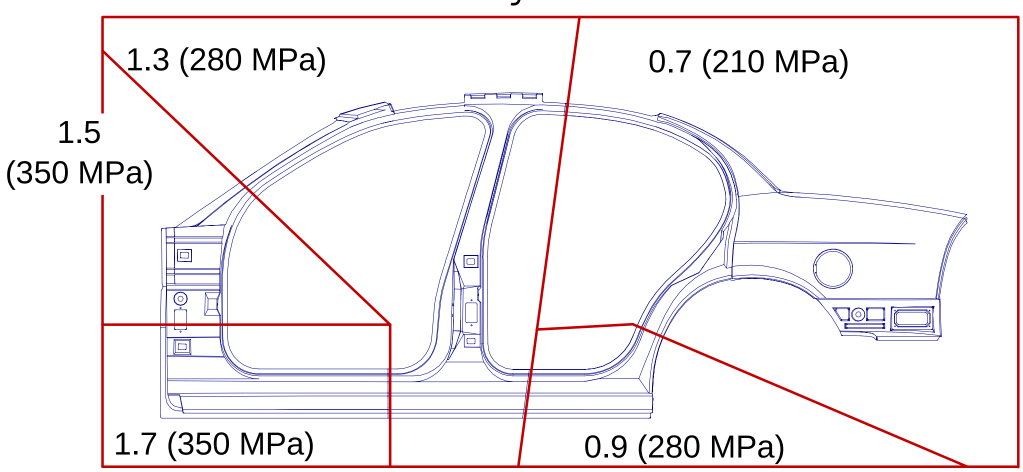
ULSAB 046 - Rail Rear Inner



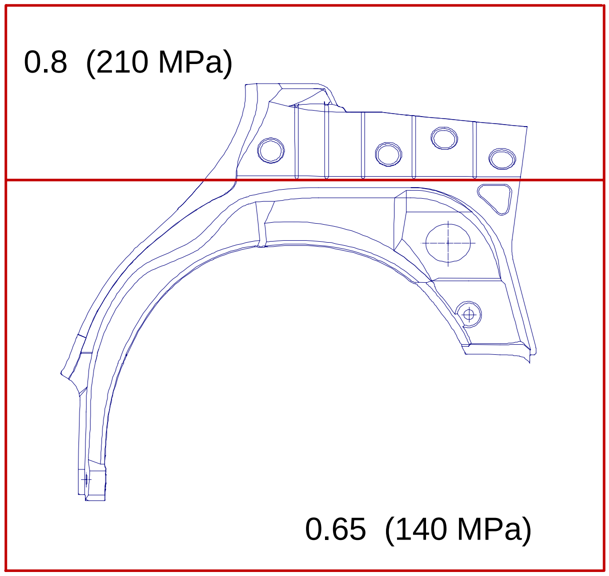
ULSAB 048 - Rail Rear Outer



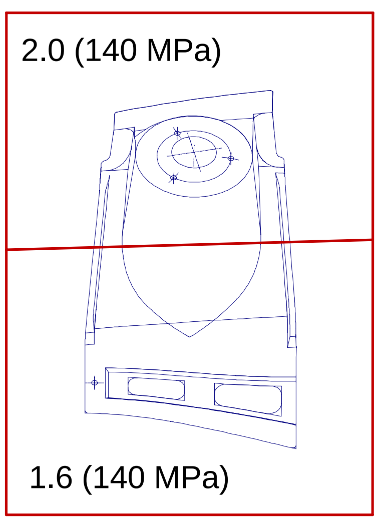
ULSAB 060 - Panel Body Side Outer



ULSAB 070 - Panel Wheelhouse Outer



ULSAB 096 - Panel Skirt



7.3.3. Production Blank Layout

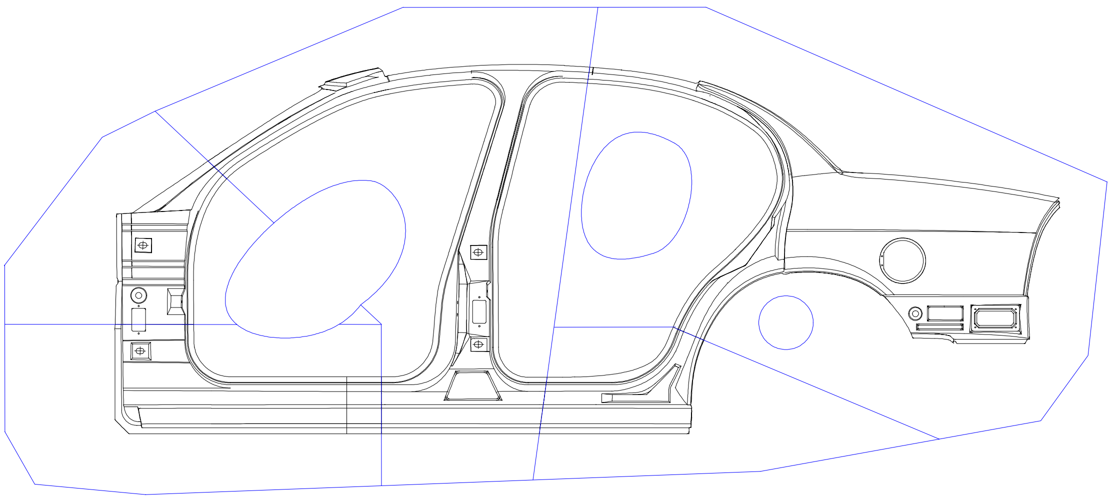


Figure 7.3.3.-1 For the Economic Analysis cost calculation purposes, the production blank layout for the tailor welded blank parts was developed.

7.4. Hydroforming

7.4.1. General Process Description

Today, tubular hydroforming is a well-established process in automotive manufacturing. When ULSAB Phase 1 began several years ago and hydroforming was chosen as the manufacturing process for the side roof rail, the technology was being used mainly for exhaust pipes and some front cradles. These had a much smaller diameter-to-thickness ratio compared to the ULSAB side roof rail. But with the focus on mass savings, it was assumed that hydroforming could reduce the number of parts while helping to optimize available package space.

The hyroforming process is described very simply as: “put a tube between a lower and an upper die, close the die, fill the tube with water and increase the internal pressure in order to force the tube to expand into the shape of the die.” However, several things must be taken into consideration within this process technology. This method will work only for straight tubes. In all other cases the tube has to be pre-bent or preformed depending on the final shape. The various steps necessary for the manufacturing of the ULSAB side roof rail will be explained in the next section.

7.4.2. Benefit for the Project

As explained in the Phase 1 report, the use of hydroformed parts instead of conventionally formed and spot-welded structures have certain apparent advantages. Because of the absence of flanges, available space could be utilized with higher efficiency (bigger cross sections were achievable). The homogeneous hydroformed parts also provide an improved load flow in comparison to other structural members made of several parts joined by spot welding. The side roof rail represents a significant structural member in the ULSAB structure and provides an optimal load distribution from the A-pillar along the roof into the B and C-pillar. This is true for the static as well as for the dynamic behavior of the body structure. Also the side impact and the rear crash support is affected positively. The interior of the vehicle is well protected by the “roll bar” design of these two structural members integrated into the body structure.

The hydroformed parts described in ULSAB Phase 1 already have led to similar applications in vehicles that are on the road today. There is a high potential for further steel applications on comparable parts that are loaded with high forces. Other opportunities for hydroformed steel structures will be in the area of protection systems for convertibles.

7.4.3. Forming Simulation (Review)

First, a feasibility check was made using the predicted bending line along with analyzing the material distribution over the circumference in different cross sections. Next, the design of the side roof rail was analyzed and optimized for feasibility by conducting a forming simulation. Simultaneous engineering was used by the team consisting of PES and the part manufacturer; a similar approach was used for the development of the conventional stamped parts.

Conducting a forming simulation for parts like the side roof rail is much more complex than for stamped parts. This is because material properties that are affected by a combination of processes such as prebending, preforming and hydroforming are very difficult to calculate. The first forming simulation has shown that wrinkles will occur during a very early stage of the forming process in the area where the tube was first prebent. The next step is to preform in a different direction to make it fit into the hydroforming tool. A picture of this area taken from the forming simulation program is shown in Figure 7.4.3-1.

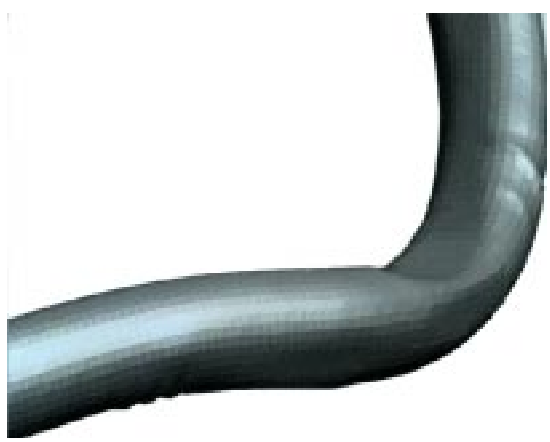


Figure 7.4.3-1 Forming Simulation

As a result of this analysis the design of the side roof rail was modified so that some bending radii were softened. Also some other areas were slightly changed in order to prevent excessive material thinning or cracking during the forming process. The forming simulation also led to the decision of using a separate preforming tool (described in Sec. 7.4.5).

7.4.4. Tube Manufacturing

Certain material qualities have to be defined. Standard tubes, beside the fact that the required diameters with the needed thin wall were not available commercially, have no high demand concerning transversal elongation. But this is one of the main factors during the hydroforming process when the tubes are expanded. Even if the difference in diameter on different cross sections of the tube is relatively low, certain areas of the ULSAB hydroformed side roof rail required a high degree of elongation. During the design process, differentiation must be made between local elongation (between two points of the circumference) and the overall elongation (total difference in circumference in a cross section). These two factors must also be taken into consideration for the longitudinal shape of the part. Transitions between shape changes of the cross sections should be as smooth as possible and high elongation is needed.

The above mentioned facts led to the decision to manufacture tubes for the ULSAB side roof rail from material different to what is used for conventional tubes. Tubes were made, therefore, from high strength steel sheets to meet yield strength requirements and to have uniform elongation in both directions. High work hardening, which should be achievable by this material, is an important factor as well.

Tubes can be made in several different ways. One way is to manufacture them with a continuous roll forming and high frequency welding. This has to be done with extremely high accuracy of the weld geometry especially on such thin walled large diameter tubes. Because the burr (which is unavoidable in this process) has to be removed in an additional planing operation (scarfing), not all of the welds are able to meet the tube specifications. Another approach is to use non-contact laser welding for the joining process. This eliminates the burr and therefore no additional operations are needed; it also creates a much-narrowed heat-affected and de-zinced zone. For these reasons the tubes for the ULSAB structure were laser welded.

For the prebending process, which requires a tube with small tolerances and a finished part with high strength, the following tube specifications were created:

Quality

Feature:	Precision steel tube according to the following tolerances
Material:	Zinc coated on both sides details see below
Yield Strength:	> 260 N/mm² (> 280 N/mm² on finished parts)
Total Elongation:	> 32% (longitudinal and transverse)
Uniform Elongation:	> 20%
r - Value:	> 1.80

Dimensions and Tolerances

Outside Diameter:	96 mm +0.1 / 0
Wall Thickness:	1.0 mm; tolerances according to ULSAB specification
Total Tube Length:	2700 mm +/- 1
Cutting of Tube Ends:	Free of Burr
	No ovalization or cave-in
	No chamfers
	Rectangular to longitudinal axis +/- 0.5°

Appearance of Tubes

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 high-frequency welding
Weld Seam Area:	Outside of tube: Undercut 0.0 mm, no expansion
	Inside of Tube: Undercut < 0.2 mm, no expansion
	No mismatch of edges
	Free of any porosity
	Strength similar to base material

7.4.5. Process Steps for Rail Side Roof

Because the side roof rail has several 2-dimensional bendings with different radii over its length and two 3-dimensional curves in the rear portion, the straight tube has to be prebent. At the beginning of the design phase, bending tubes with such a high diameter (96 mm) -to-wall-thickness (1.0 mm) ratio resulted in very poor bend quality. At first, the tubes were bent by using a conventional mandrel-bending machine modified in such a way that the mandrel was replaced by internal fluid pressure. This inside pressure is working as a substitute for a mandrel. The purpose of this was to maintain stricter tolerances which are directly related to the accuracy of the bending tools, the diameter of the mandrel used, and the tube diameter and wall thickness. In this way, the tubes could be bent into the needed shape without any wrinkles. However, because the pressure was applied inside the whole tube, the tube diameter increased to a point that the tube would not fit into the next die. Therefore, Porsche went back to using the solid mandrel. By holding to stricter tolerances and taking certain other steps, wrinkle-free tubes could be formed. With this process, the clamping force needed to avoid wrinkles or damage to the tube has to be kept within a tight tolerance.

Once the tube is prebent, preforming is the next step. This is done in a three-piece tool under low internal pressure to avoid collapsing. The tube is then flattened and bent again in order to fit into the final hydroforming die. The basic layout of the preforming tool and the tool itself is shown in Figure 7.4.5-1, 2 & 3.

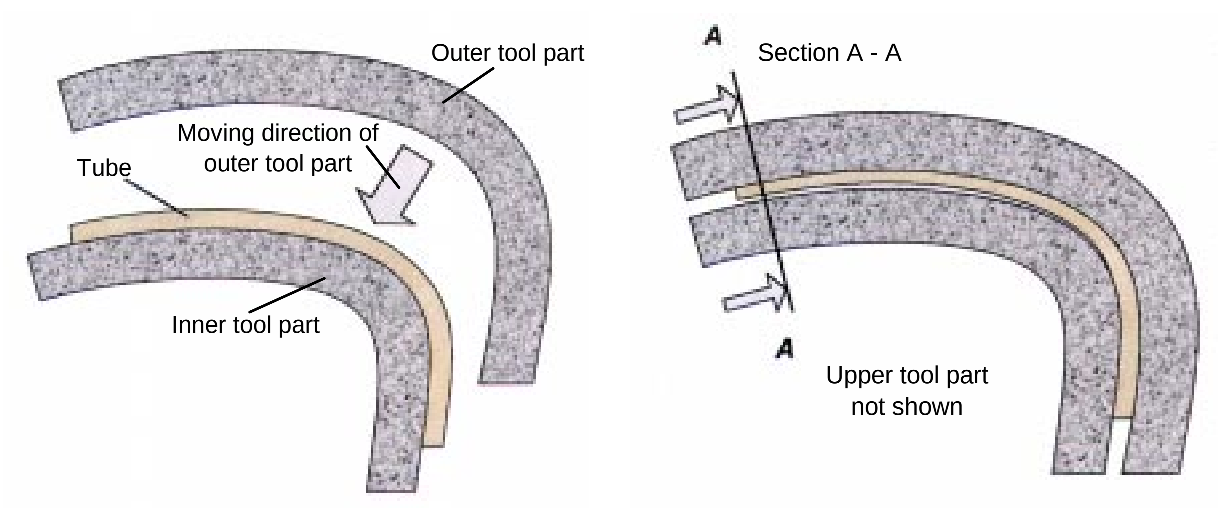


Figure 7.4.5-1 Preforming Tool Concept

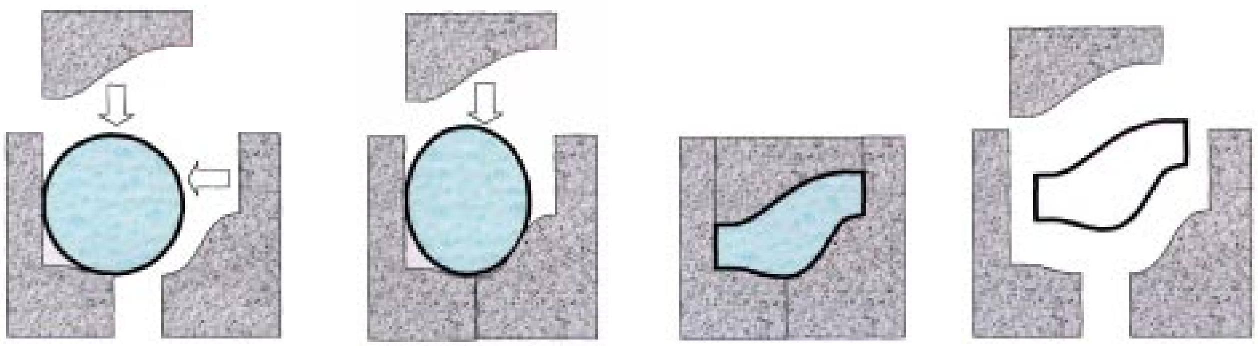


Figure 7.4.5-2 Sec. A-A of Preforming Tool Concept

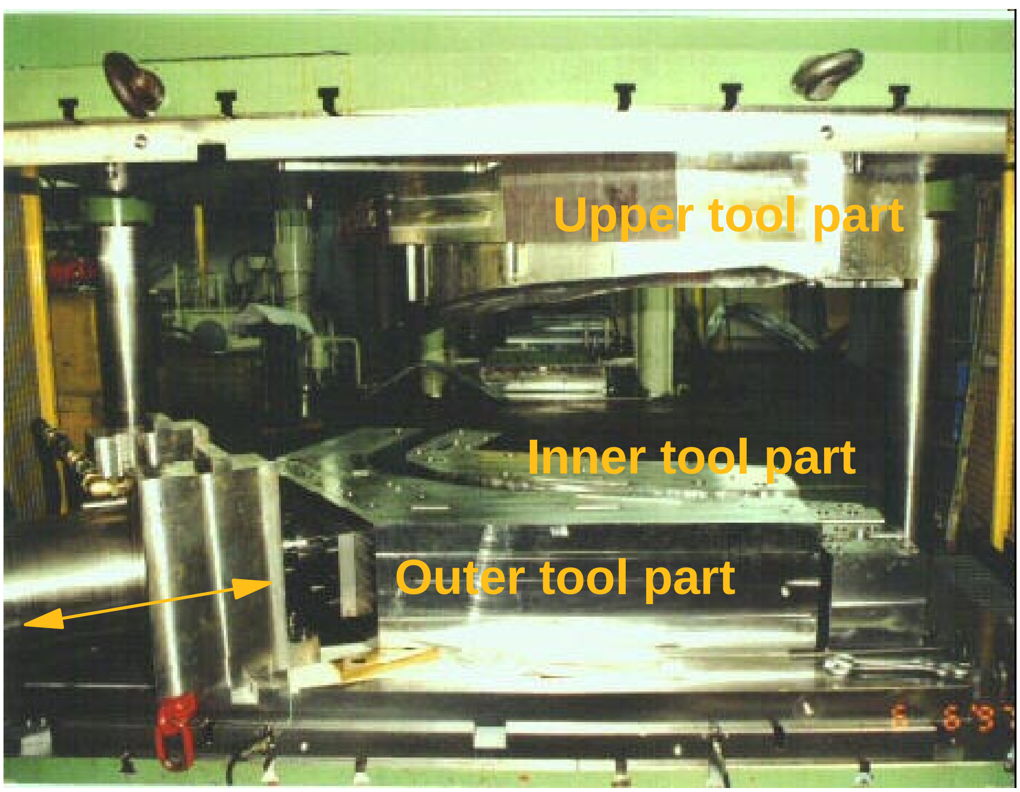


Figure 7.4.5-3 Preforming Tool

The final step is the hydroforming process itself. During the down movement of the upper half of the die there is another area preformed again (under low internal pressure) on the tube. This must be done because the hydroforming process is very sensitive to die locking. Once the die is finally closed, the internal pressure is increased and the side roof rail tube is calibrated into its final shape. The pressure has to be raised to 900 bar for the side roof rail in order to set the final shape of the part. This required a closing force of about 3200 tons. This internal calibration pressure was higher than predicted by calculation and forming simulation. A picture of the hydroforming tool is shown in Fig. 7.4.5-4.

Figure 7.4.5-4 Hydroforming Tool

7.4.6. Results

Hydroforming has never been used previously to form a high strength steel tube with such a high diameter-to-wall-thickness ratio. Nevertheless the goal to manufacture the side roof rails was achieved. There is still room for improvement, but the main problems related to the bending and preforming operations were resolved. Hydroforming will be only a calibration operation if all-important steps before this were optimized. With the experience gained from the ULSAB Phase 2, producing similar hydroformed applications should be easier in the future.

7.5. Hydromechanical Sheet Forming

7.5.1. General Process Description

Hoods, roofs and door panels (large body outer panels) produced by conventional forming methods often lack sufficient stiffness against buckling in the center area of the part. Due to the low degree of deformation in the center, there is only a little work hardening effect that could be achieved. Therefore, material thickness has to be increased to meet the dent resistance requirements on those parts. This of course leads to heavier parts and creates extra costs. The “active hydromechanical sheet metal forming process” is a forming technology that uses an active fluid medium. The die consists of three main components: a drawing ring, which is designed as a “water box,” the blankholder (binder) and the drawing punch itself. At the beginning, the die is open and the blank is loaded on the ring (see figure 7.5.1-1).

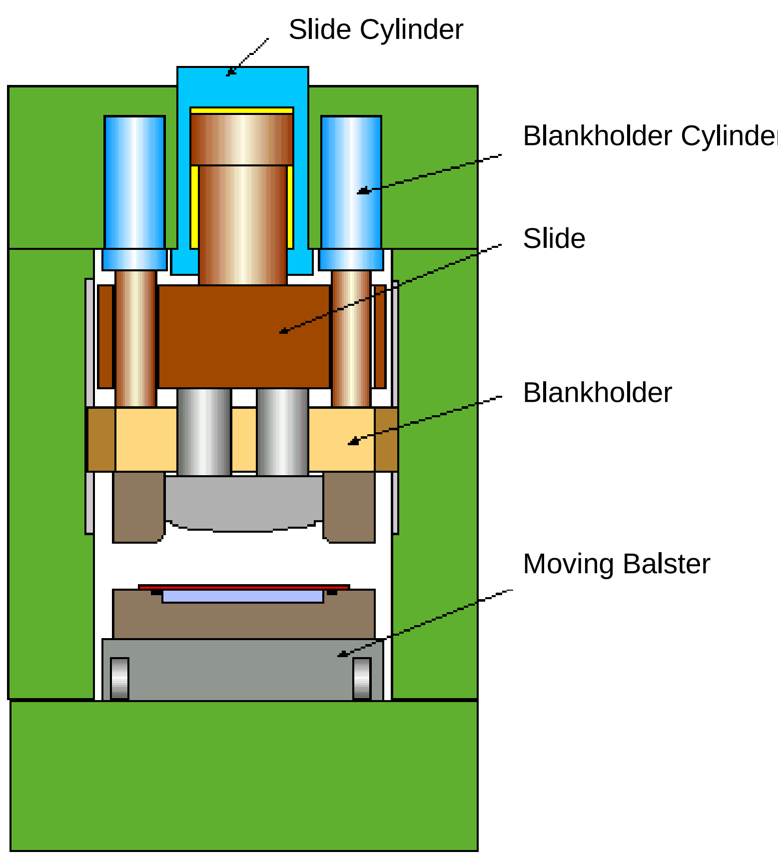


Figure 7.5.1-1 Active Hydro-Mec Process Step: Loading / Unloading

In the second stage, the die is closed and the blankholder clamps the blank. The die punch has a defined, part specific regress against the clamped blank, as in figure 7.5.1-2. A pressure intensifier is used to introduce the water emulsion into the water box, where a pre-set pressure is generated. The blank is inflated in a controlled manner and stretched over the complete area until it is pressed against the punch. This is the reason why the process is called "active hydromechanical sheet metal forming." Forming with fluids (or flexible rubber layers) is well known already, but previously there was no forming in the "opposite" direction within those processes. The plastic elongation produces a work-hardening effect, especially in the center of the part. This effect significantly improves the dent resistance of the formed part.

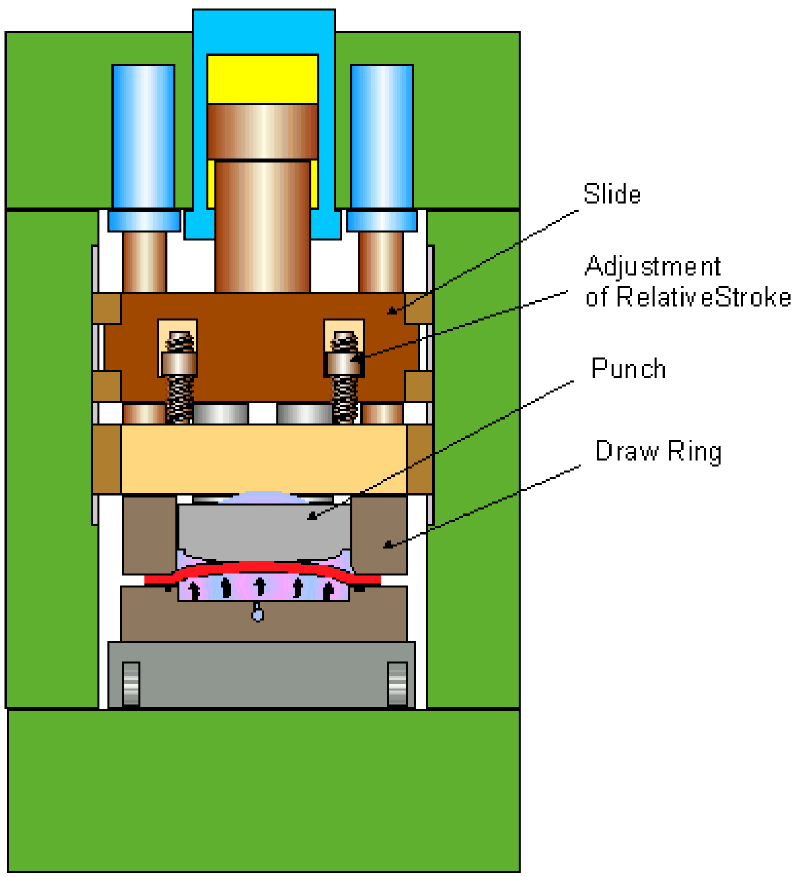
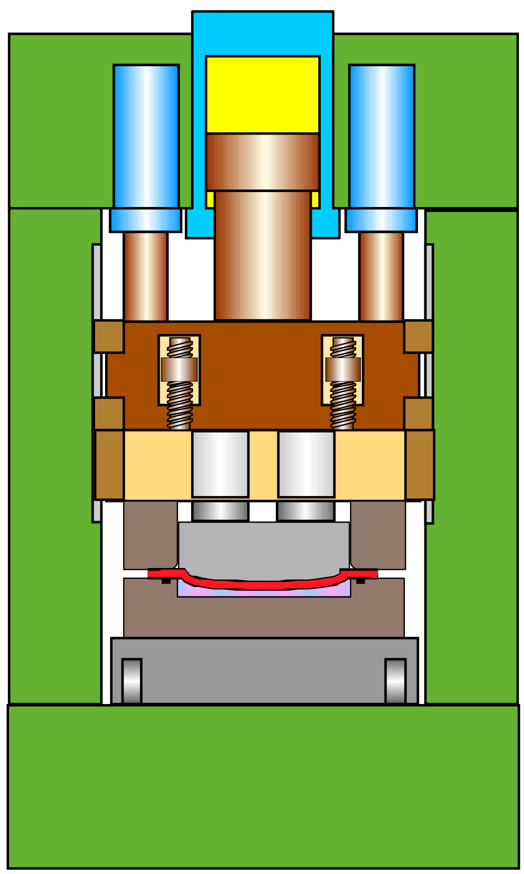


Figure 7.5.1-2 Active Hydro-Mec Process Step: Pre-forming

Once the first plastic elongation process is done, the draw punch is moved downward, as in figure 7.5.1-3. At the same time, the emulsion is evacuated from the water box and the pressure of the fluid is lowered in a controlled process. After completion of the drawing operation, pressure is increased once more in order to calibrate the part into the final shape. The later visible surface of the part (outer side) is turned towards the active fluid medium. There is no contact to metal on this surface and an excellent surface quality of the part was achieved.



Source: SMG Engineering Germany

Figure 7.5.1-3 Active Hydro-Mec Process Step: Forming Completed

A picture of the formed roof panel is shown below in figure 7.5.1-4.

Figure 7.5.1-4 Roof Panel

7.5.2. Benefit for the Project

The active hydromechanical sheet metal forming process is characterized by improved component quality and potential mass and cost reduction. The essential features of this new technology are: higher dent resistance achieved by an increased work-hardening effect during the first “counter” forming operation, and superior visible surface quality achieved by using water instead of a metal die for the final forming operation. This leads to a reduced component mass due to increased stability. Sheet thickness could be reduced to 0.7 mm and reinforcement elements could be saved, while all other requirements were still fulfilled. In addition, the cost of dies can be reduced by about 40% because only one polished half of the die is required. In addition, the average lifetime of the dies will last longer, under mass production conditions, than usual because there is little wearing off when forming with a fluid medium.

In order to get the most benefit out of this process a forming simulation should be performed. This simulation may help to predict the maximal prestretching amount achievable without damaging the sheet. The absence of friction between the blank and the conventionally used second half of the die makes the result of the simulation very reliable. Furthermore, the process parameters, (e.g., preforming pressure, etc.) could be easily adjusted.

7.5.3. Process Limitations

Depending on the grade of prestretching, which is related to the preforming pressure, the size of the forming press (locking force) has to be chosen. This is also influenced by the overall projected area of the part (e.g., for the ULSAB roof panel, a press with a locking force of 4,000 was chosen.) A double (or triple) action hydraulic press must be used to make the process reliable.

This press can be used for conventional forming, and with the use of some additional equipment, for the tubular hydroforming process.

The filling time for the fluid medium pressure bed has to be taken into account as well. This leads to a calculated cycle time for the ULSAB roof panel of about 30 - 40 seconds. Depending on the design of the part, this has to be compared to a two-step conventional forming operation.

Due to potential die locking, it appears that an undercut on the hydroformed parts is not feasible in this process without using a separate tool. This is also relevant for the cutting of flanges. This has to be done separately using laser or conventional trimming operations.

7.5.4. Results

Roof panels for the ULSAB could be manufactured by using the active hydromechanical sheet metal forming process. Different material qualities, like isotropic, IF and bake-hardening types, were formed successfully. Due to the work-hardening effect, which was applied through the above-described process, the sheet thickness of the roof panel could be lowered to 0.7 mm, while the dent resistance requirements were still met.

In order to limit the needed locking force of the press, the flange radii should be designed not too small. The radii are directly related to the needed pressure during the final forming operation, and if too small lead to an uneconomic high-locking force/press size. The surface quality on the visible side of the ULSAB roof panel, which was not in contact with any metal tool, was very high compared to conventional formed (prototype) parts.