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Hydroforming of Large-area Multi-cell Sheet Metal Structures

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Abstract. This paper presents a sectionwise hydroforming technique for manufacturing of large-area multi-cell sheet metal structures in terms of hump plates. The sectionwise hydroforming technique allows production of hump sheets with variable width and length. The hump plates are based on hexagonal hump geometry. The hump height is optimized for the application as a partition wall in light utility vehicles. Manufactured hump sheets feature a high contour accuracy which allows joining of two hump sheets to a large-area hump plate (up to 1,800 x 2,000 mm). The hump plates have been successfully tested in a load test which proves their potential for light utility vehicles.

Introduction

Lightweight design is gaining increasing importance for economic and ecological reasons. The use of multi-cell steel structures (e.g. hump plates) is an important approach for economic lightweight design due to their high stiffness and strength compared to conventional sheet metal parts. Furthermore, hump plates with standardized hump shapes for various applications can be produced in large quantities [1-5]. Especially in light utility vehicles, numerous potential applications for the use of large, planar structures exist [5-8]. Steel hump plates, like the *borit*®-plate, have already been an attractive solution for planar, small-area structural parts of the automotive industry for many years [9].

Manufacturing of hum sheets by hydroforming has three major advantages; excellent contour accuracy of hydroformed humps which is essential for subsequent joining processes, homogenous strain hardening, and the optimal use of material formability. Fig. 1 shows a comparison between embossing and hydroforming of a hump in terms of contour accuracy and strain distribution. Current restriction of the hydroforming technique are the comparatively long pro cycle times, the demand on high locking forces and expensive press machines if high fluid pressures are applied onto large-area blanks. Hence, hydroforming of large-area parts is a difficult challenge. A proved measure to produce hump sheets with unlimited length is the section wise hydroforming technique (see fig. 2).

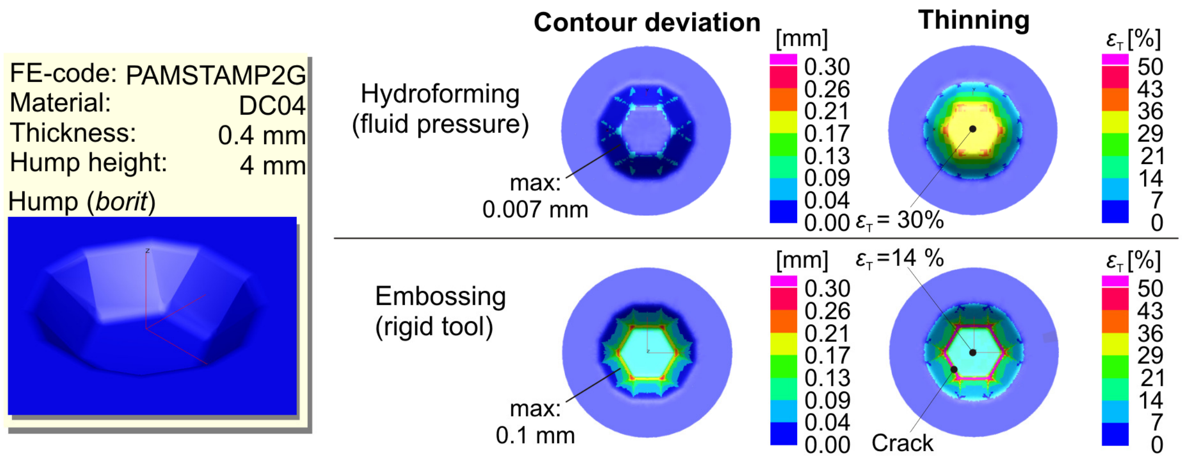


Fig. 1: *Embossing and hydroforming of a hump*

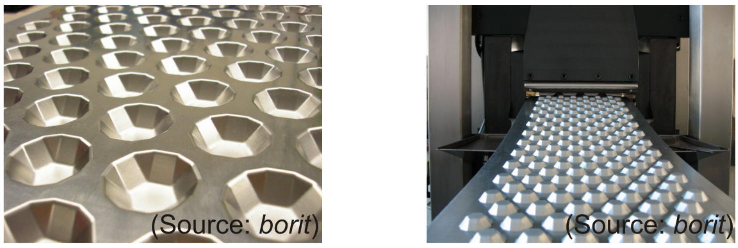
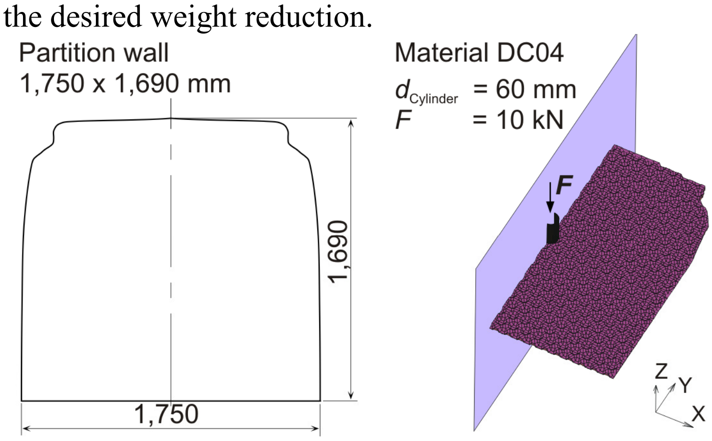


Fig. 2: *Hump plate with hexagonal structure (left) and sectionwise hydroforming (right) [10]*

However, applications in utility vehicles (e.g. partition walls) demand the manufacturing of large-area hump plates. Hence, use of hump plates is restricted because the oblong hump sheets have to be joined with overlaps to large-area structures. This results in an increase of joints and high manufacturing costs. To prove the feasibility of large-area hump sheets, this paper presents a new hydroforming tool system for conventional press machines, and the results of hydroforming of the hump sheets and loading test of the final hump plates.

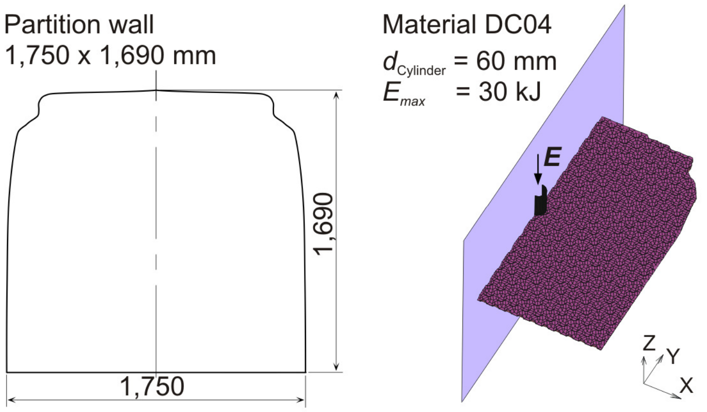
Scaling of hexagonal hump geometries for load cases of utility vehicles

In order to get realistic conditions, the *borit*® hump geometry was optimized with respect to specific load cases for utility vehicles defined in *Standard 2562* [11], [12]. This standard includes an area loading test and a notch test which were modeled using the FE-code *MSC.MARC 2005*. In the numerical study, depth of the hump geometry and sheet thickness was varied systematically. The boundary conditions were adapted to real fastening conditions (screw). The deformation results of both tests show, that a hump depth of 8 mm and a sheet thickness of 0.4 mm are optimal parameters (fig. 3 and fig. 4). Other parameter combinations do not meet the load requirements of the standard and the desired weight reduction.



Hump depth in mm	Thickness in mm	Indentation in mm
4	0.3	Failure
	0.4	
8	0.3	171
	0.4	108

Fig. 3: *FE-model of area loading test and determined deformations*



Hump depth in mm	Thickness in mm	Indentation in mm
4	0.3	Failure
	0.4	
8	0.3	320
	0.4	190

Fig. 4: *FE-model of notch test and determined deformations*

Tool System for Sectionwise Hydroforming

The economic and technical constraints impose the following requirements on the hydroforming tool:

- high robustness of the process
- high contour accuracy of the hump sheets
- adequate sealing of the tool cavity up to the required maximum pressure
- prevention of leakage as a result of tool defection
- prevention of flange draw-in
- accurate feed motion and positioning of the blank
- limitation of locking forces to 10,000 kN

The tool features a small pressurized tool area which limits the locking forces for the required fluid pressure. Previous forming test proved that a fluid pressure of 50 MPa leads to adequate shape accuracy of the hump sheet. Fig. 5 shows a cross-section of the hydroforming tool. The tool system was operated in a conventional hydraulic press machine (*Müller Weingarten*) with a maximum press force of 10.000 kN (see fig. 6).

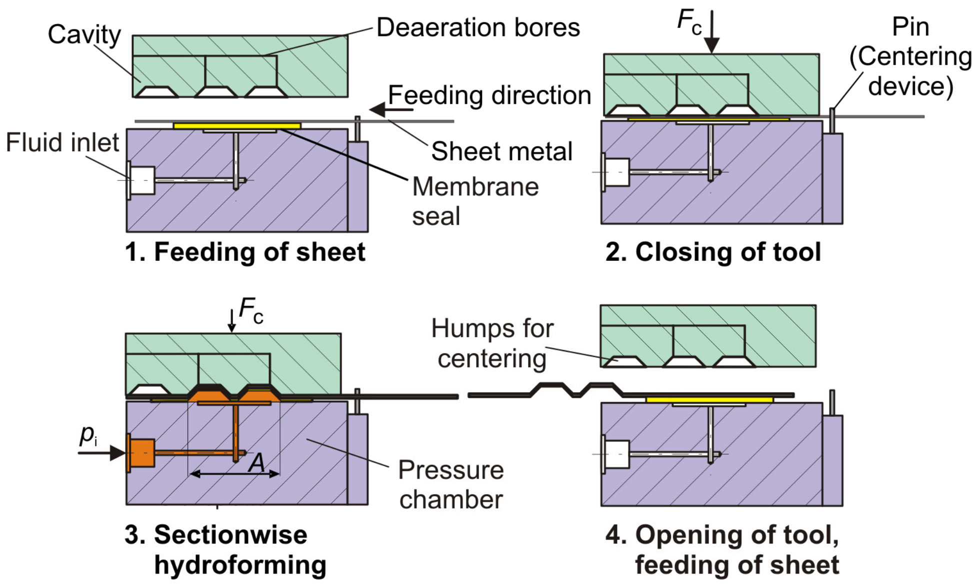


Fig. 5: *Sectionwise hydroforming of hump sheets*

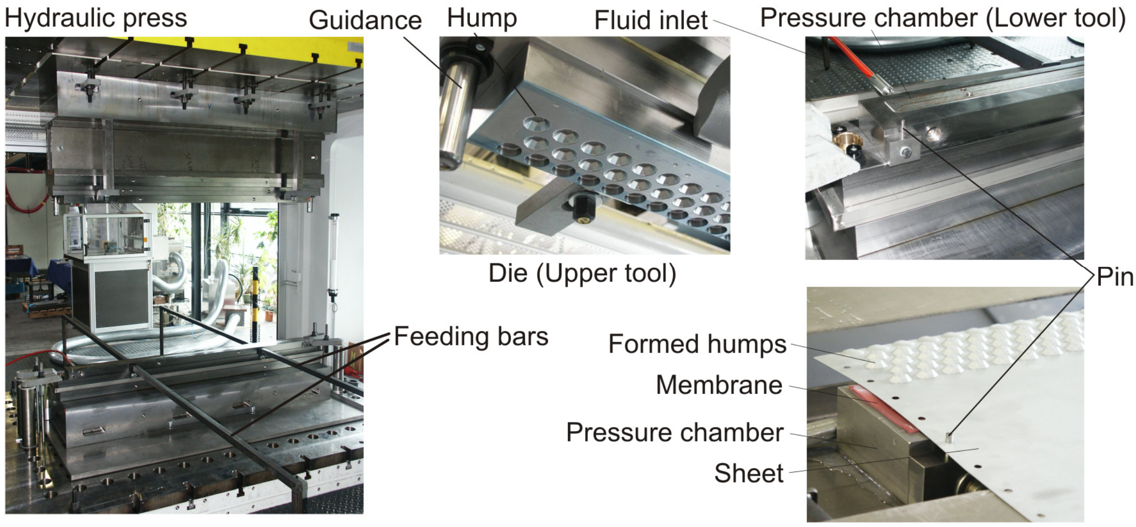


Fig. 6: *Sectionwise hydroforming process - experimental setup*

Two hump rows are formed simultaneously with every stroke. A third row of hump cavities supports the feed motion and positioning of the blank. The clamping area was designed with consideration of the maximum locking force and yield strength of the sheet material. The sealing during the hydroforming process is provided by a highly elastic PU-diaphragm seal which is positioned between the die and the pressure chamber. To increase the process robustness, the seal is mounted at the pressure chamber to ensure its fixed position. The pressure chamber is positioned underneath the die cavity. Hence, the sheet is pressurized from the bottom side, enabling a reflow of the fluid media into the pressure chamber at the end of the process. To generate the required fluid pressure, an external plunger pump is used.
Feeding bars allows the part handling up to an area of 1,800 x 2,000 mm. The feed motion was manual. Several alignment methods were tested in order to optimize position accuracy between the strokes. In tab. 1 the position accuracy per stroke of different alignment methods are compared using a special measuring device. Locator pins in combination with two rows of laser-cut holes in the blank enable high position accuracy and were therefore used in the forming tests.

Tab. 1: *Comparison of alignment method*

alignment method	position accuracy per stroke
third row of hump cavities (self alignment)	app. + / - 0.9 mm
blank marks (visual alignment)	app. + / - 0.7 mm
stopper (mechanical alignment)	app. + / - 0.6 mm
blank with laser-cutted lug (mechanical alignment)	app. + / - 0.4 mm
locator pin and blank with laser-cut hole (mechanical alignment)	app. + / - 0.1 mm

Hydroforming of Large-area Hump Sheets

For the hump sheets, mild steel (DC04) with thicknesses of 0.32 mm and 0.40 mm and a 1,862 x 1,900 mm blank cut were used. Since such large-area formats were not available, two medium-size blanks were joined by laser welding to a large-area blank cut. Because of the reduced formability of the weld seam, the alignment method must assure that the accumulative positioning error is low enough to allow the weld seam to be accurately positioned onto the clamping area (outside the plastic forming zone). During the test, a fluid pressure of 50 MPa was applied and the PU-diaphragm avoided leakage up to this pressure. Fig 7 shows the hydroformed hump sheets.

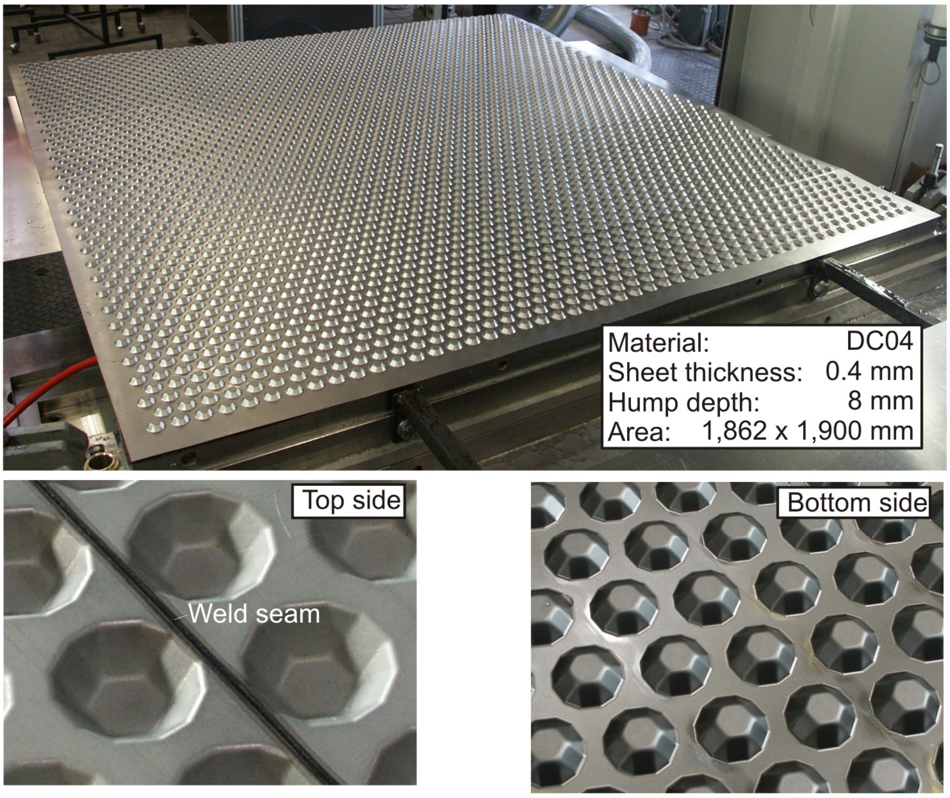


Fig. 7: *Hydroformed hump sheets*

Since the hump sheets are semi-finished products for hump plates, the accuracy of the hump shape and the position accuracy of the humps along the feeding direction are essential for the joining process. Using the optical contour measurement system ATOS (*GOM*), the shape accuracy and the position accuracy (see fig. 8) are detected.

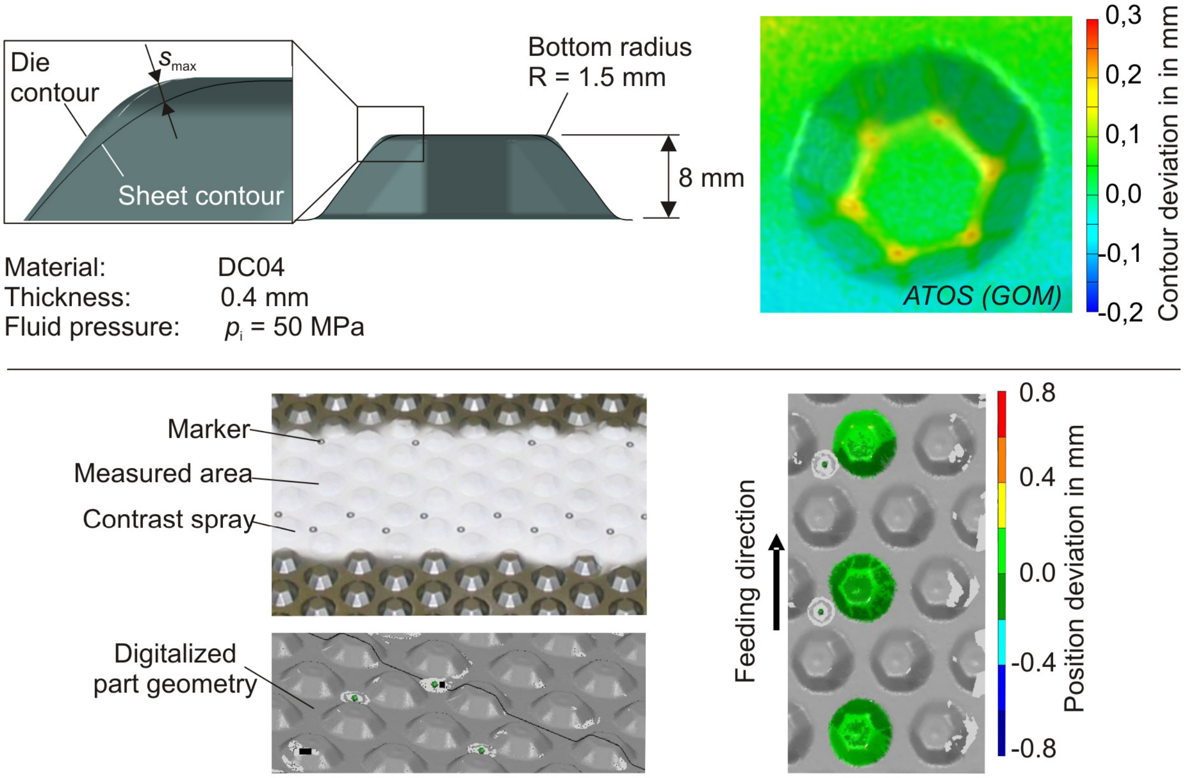


Fig. 8: *Accuracy of the hump shape and position accuracy of the humps in feeding direction*

The hump shape features small bottom radii and accurately shaped side wall, which are the contact surfaces between the hump sheets after joining. The accurate contour assures a high contact area which has a positive effect on the final stiffness of the hump plates. Fig. 9 shows the strain distribution in the forming zone, measured with the optical strain measurement system ARGUS (*GOM*). The humps show a high level of plastic strains. The clamping zone is nearly not affected by the hump bulging (there is no flange draw-in). According to the forming limit diagram, the formability is extensively used but the process is still robust in accordance to the experimental experience gained by retests.

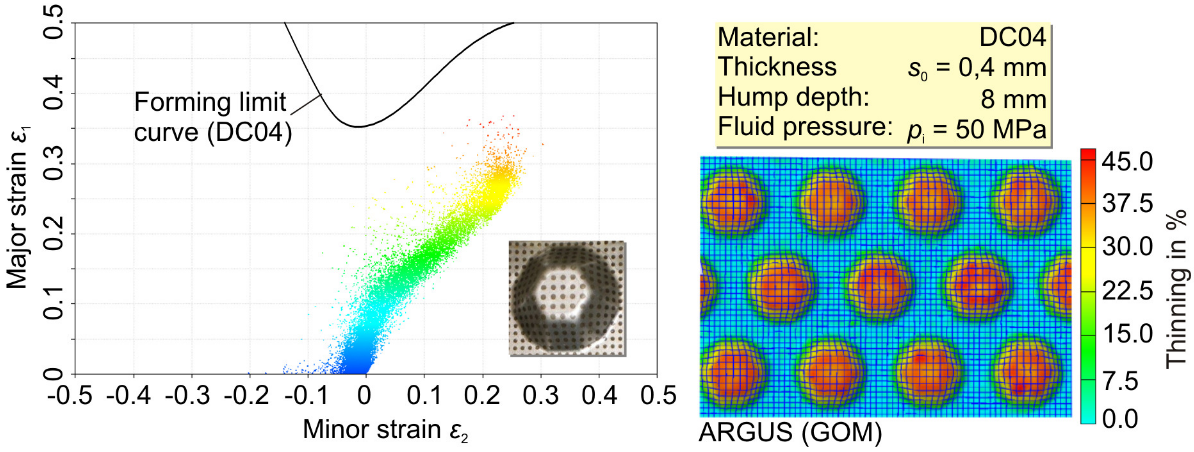


Fig. 9: *Strain distribution*

Manufacturing of Hump Plates and Load Tests

Two hump sheets were joined successfully to a hump plate by laser welding. The laser welding process was performed at *ThyssenKruppSteel AG* applying a joint at the bottom of every hump (fig 10).

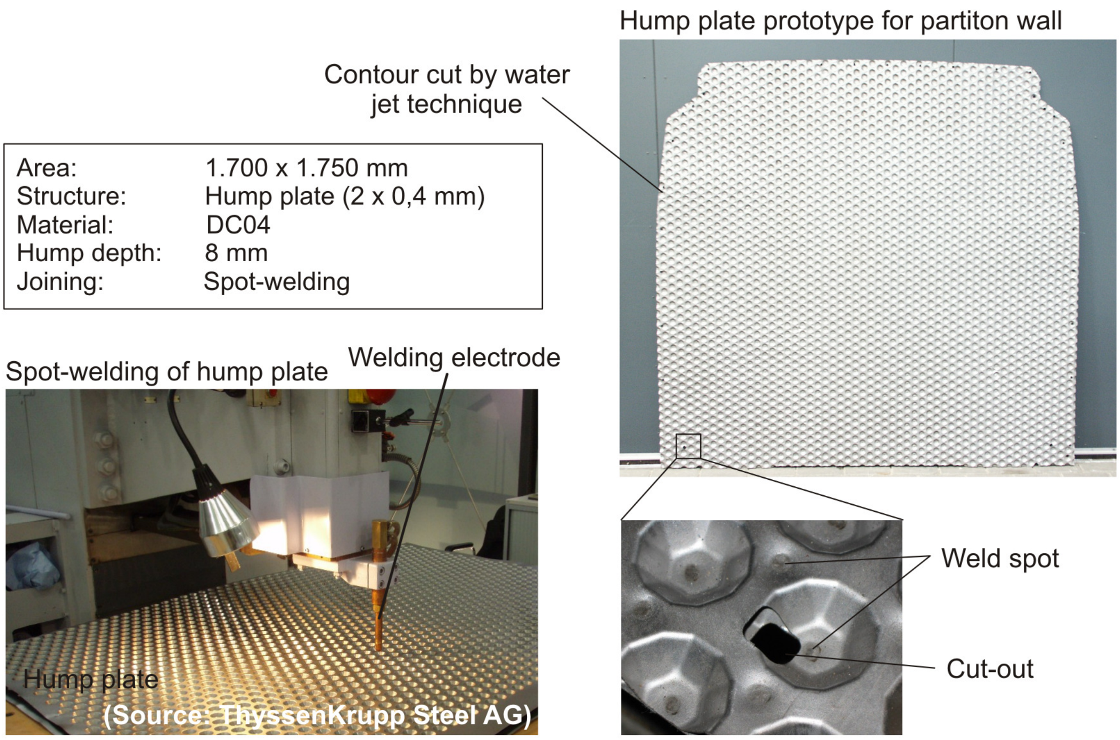


Fig. 10: *Realized prototype hump plate for application as partition wall of a light utility vehicle*

The final plate cut and the fastening holes were obtained by jet cutting. The area of the cut plate matches the partition wall of a utility vehicle (1,700 x 1,750 mm). Compared to the currently existing partition wall of the serial production (deep drawing part), the hump plate offers a weight reduction of 20 %, while preserving the same stiffness.
The produced hump plate was tested at Volkswagen AG by an indentation test (German standard DIN 75410-3). Fig. 11 shows the experimental setup for load test which simulates the load of moving freight during braking. Fastening of the hump plate is the same fastening of the deep drawn partition wall. The hump plates successfully passed the indentation test for 3,5t utility vehicles without failure in the sheet material or at the joints.

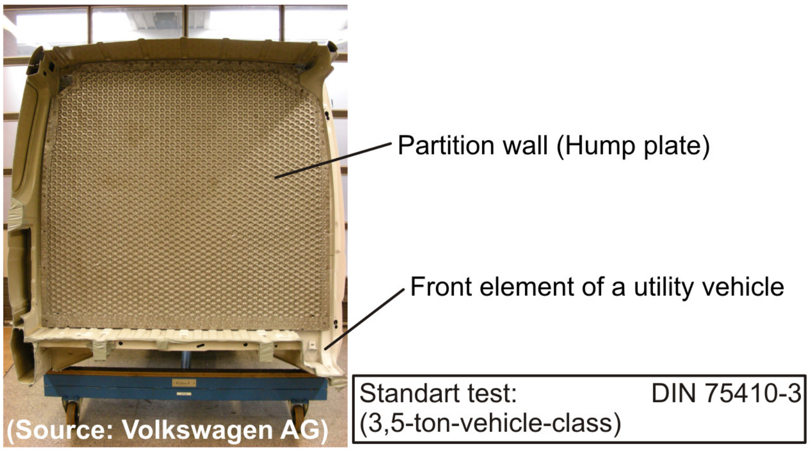


Fig. 11: *Experimental setup for load test conducted at Volkswagen AG*

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Summary

Based on large-area blank cuts which are produced by laser welding of two conventional middle format sheet metals, large-area hump sheets with variable widths and length were manufactured by sectionwise hydroforming. The hump plates are based on a hexagonal hump geometry with hump height which is optimized for the application as a partition wall in light utility vehicles. The developed hydroform tool which was used in the experimental study ensures high process robustness. The robustness is due to effective prevention of tool defection and special membranes used as sealing for the tool cavity. The necessary locking forces could be limited to 10,000 kN because of the reduced pressurised tool area. The hydroformed hump plates feature a high contour and position accuracy of the hump sheets which is essential for the subsequent joining of the blanks to hump plates. Centering pins assure an accurate positioning of the blank. The accumulated positioning deviation is very low, therfore the weld seam can be reliably positioned outside of the forming zone. Based on the hydroformed hump sheets, large-area hump plate with an area up to 1,800 x 2,000 mm were produced by welding. The hump plates have been successfully tested in special load test proving their excellent properties and high potential for light utility vehicles.

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