

Lightweight Potential of Ultra High Strength Steel Tubular Body Structures

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ABSTRACT

Hot-formed steels, also called "Boron steels" or Ultra-High Strength Steels-UHSS, offer a great weight saving potential versus conventional cold-formed high strength steels used for crash relevant structural parts.

Boron steels allow complex shaped parts due to the hot-forming process. In the hot forming process first the sheet metal with initial yield strength of around $\sigma_y=400$ MPa is blanked and then heated in an oven up to $\sim 950^\circ$ Celsius. In the next step the "hot" sheet metal is stamped and at the same time rapidly cooled down and quench hardened in the stamping die.

During this process the yield and ultimate tensile strength increase up to approximately $\sigma_y>1100$ MPa and UTS ~ 1500 MPa in the final stamped part. The enormous strength and the very good dimensional tolerances with nearly no springback result in the use of more and more hot-formed parts in the body, especially for crash relevant parts like structural reinforcements.

Hydroforming enables tubular designs and is applied in high volume production for body structure parts. Tubular designs are structurally very efficient, because of the closed section & continuous joint in the tube. But for complex shaped body parts hydroforming is nowadays limited to cold formable Advanced High Strength Steels (AHSS) with strength up to UTS ~ 1000 MPa.

The ACCRA process combines the benefit of hot-forming and hydroforming by enabling tubular designs with quench-hardened Boron steel mechanical properties. ACCRA is a trade name for several forming and hardening processes for tubular designs. The focus in the paper will be on the Form-Blow Hardening (FBH) process. In this process a tubular Boron steel pre-material is going through a process of hot-forming, air-pressure forming and water quenching resulting in a tubular structure with an ultimate tensile strength of UTS ~ 1500 MPa.

The paper will give an overview on

- The ACCRA process including FBH,
- The benefits of tubular UHSS designs compared to conventional stamped designs
- Application samples to demonstrate the lightweight potential of Boron tubular steels designs for structural applications.

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INTRODUCTION

There is a trend in the industry to use more and more Boron steels in the body structure to enable lightweight design and enhanced crash performance. Figure 1 roughly shows the body structure of the current Ford Focus. Boron steel parts are used for A- / B-Pillar reinforcements and highlighted in red color.

The front and rear bumper beams are also made of Boron steel, but not shown here. The manufacturing process for such parts is the hot-forming process, resulting in parts with excellent geometrical

tolerances and ultra-high strength mechanical properties. Exemplarily in Figure 2 and Figure 3 the A-pillar of the current Ford Focus is shown. Both hot-formed parts are spot-welded to an assembly, building a closed section. The outer side panel and small attachments parts are not shown in this figure.

Hydroforming enables tubular designs and is applied in high volume production for body structure parts and has a long successful history within the Ford Motor Company. Tubular designs are structurally very efficient, because of the closed section & continuous joint in the

tube. This can help to avoid spot welding and heat affected zones in highly stresses areas of the parts. But for complex shaped body parts hydroforming is nowadays limited to cold formable Advanced High Strength Steels (AHSS) like DP1000.

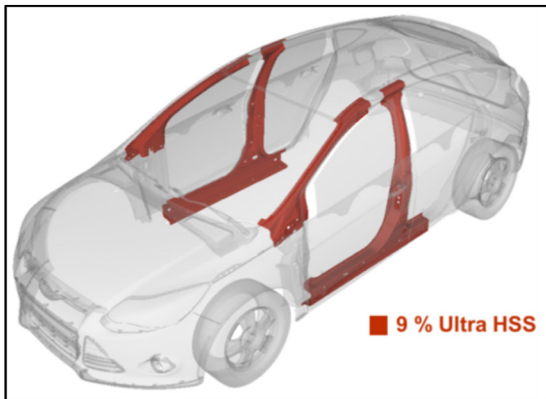


Figure 1. Body Structure of Ford Focus (red: Boron steel parts)



Figure 2. Materials and thickness distributions of a typical A-Pillar in shell design

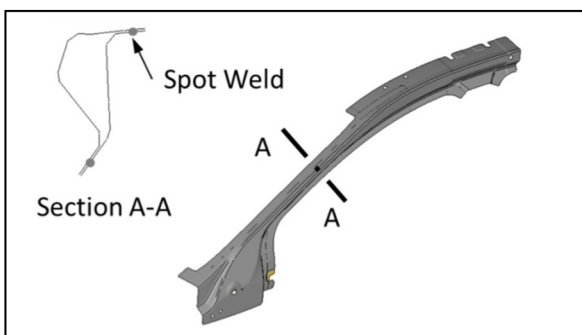


Figure 3. A-Pillar in shell design and x-section. The two parts are spot-welded together with the outer panel (outer panel not shown).

Exemplarily the body structure of the current Ford Fusion is shown in Figure 4. The A- and B-pillar reinforcements are formed in a low pressure/pressure sequencing hydroform process.

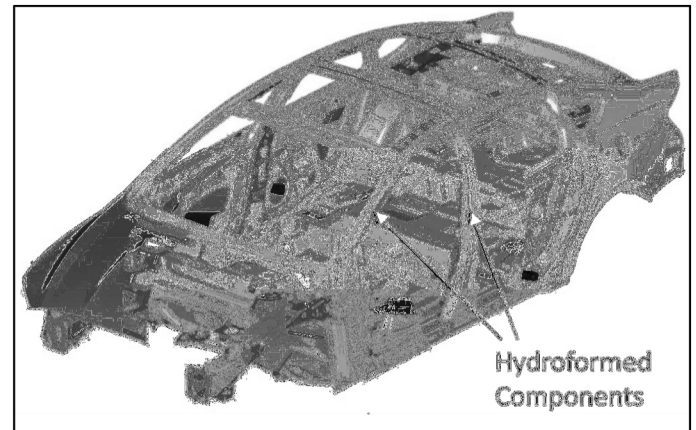


Figure 4. Body Structure of Ford Fusion (source: [1])

In Figure 5 the hydroformed A-pillar tube of the Ford Fusion with a variable cross section over the length is shown. Several other brackets are welded to this tube to build the final A-pillar assembly (these brackets are not shown). The material grade is a dual phase steel grade with ultimate tensile strength of UTS~1000 MPa.

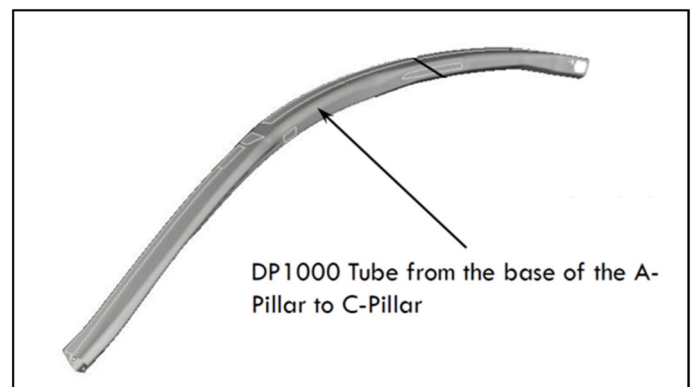


Figure 5. Hydroformed A-Pillar of Ford Fusion (source: [1])

At the moment the majority of the hot-formed parts are produced in Europe, while the US is more focusing on low pressure hydroforming. Currently hot-forming enables a material strength up to UTS~1500 MPa, but is limited to stamped parts for industrial production.

Hydroforming on the other side enables tubular designs, but for complex shaped vehicle parts at the moment the strength level ends at approximately UTS~1000 MPa. Steel grades with higher strength are at the moment not in industrial use for complex body parts, see [1].

Lightweight Potential of UHSS Compared to AHSS

The benefit of using tubular designs made of Boron steel with UTS~1500 MPa compared to AHSS steel grades with lower UTS (here DP1000 with UTS~1000 MPa and DP800 with UTS~800 MPa) is investigated. In Figure 6 a simple quasi-static 3 point bending test of a tubular profile (section size 50 mm × 50 mm, length 600 mm, fixture distance 500 mm) is shown. A Boron steel profile with a thickness of 1.3 mm is taken as the reference.

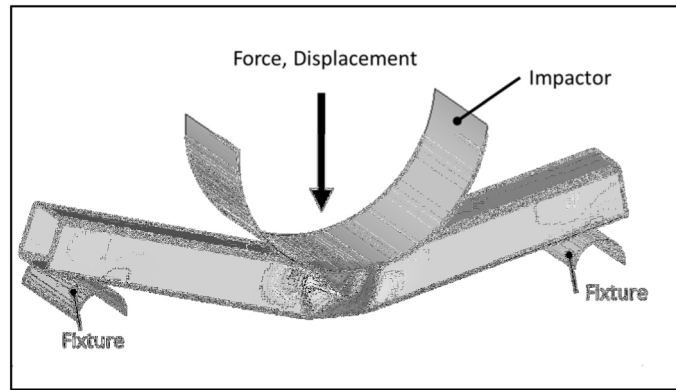


Figure 6. 3-point bending test on a tubular profile

Figure 7 shows the Force/Displacement characteristics of the different materials and thicknesses and equivalent bending capacities, measured in maximum peak force and energy absorption as a function of the impactor displacement.

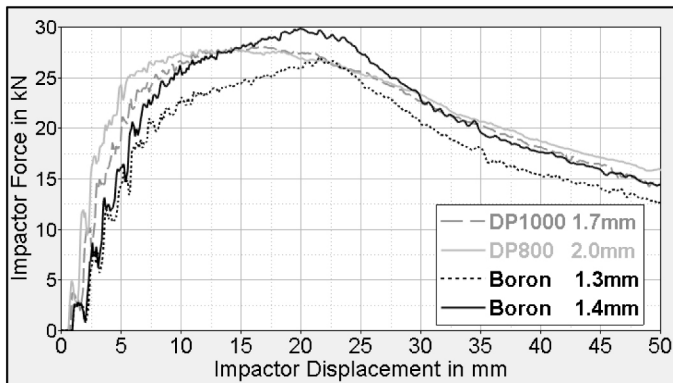


Figure 7. Force-Displacement characteristics for different steel grades with similar structural performance (energy absorption and peak force)

For DP1000 the weight increase compared to the baseline in order to obtain the same peak force is approximately 30 %. In order to achieve the same energy absorption, the weight increase is 22%. For DP800 the weight increase is approximately 40 % and >30 % for the same energy absorption. For all chosen materials the deformation is far from fracture limits. The weight situation might get a little bit better for the dual phase steels when signification forming effects in terms of work hardening due to stretching can be introduced during the hydroforming process. In Figure 8 the results are summarized.

		Boron	Boron	DP1000	DP800
t_profile	mm	1.30	1.40	1.70	2.00
Weight	%	100	108	131	143
Peak Force	%	100	110	103	103
Energy	%	100	114	114	119

Figure 8. Weight saving potential of quench-hardened Boron steel tubes compared to low-pressure hydroformed dual phase steel tubes.

The results show that tubular designs in Boron steel enable a significant weight saving versus hydroformed designs in AHSS at the same structural performance.

Therefore manufacturing processes which can combine the main benefits of both processes (tubular design by hydroforming, ultra high strength mechanical properties and excellent geometrical tolerances by hot-forming) would be a valuable option for advanced lightweight structure designs. In the next chapter production processes will be described.

MANUFACTURING PROCESSES FOR BORON TUBES

For the production of tubular designs in Boron steel special manufacturing methods are necessary. In contrast to conventional press hardening, which uses sheet metal blanks as pre-material, the ACCRA-Process by Linde + Wiemann works with closed profiles. A second process, the InnForm T³ process developed by ThyssenKrupp Steel Europe can be used to generate tubular designs, which can be used as pre forms for a direct heating/quenching or for the ACCRA process.

ACCRA-Process (Form-Blow Hardening)

The ACCRA manufacturing process combines well known manufacturing processes in a special way. Pre-material can be rollformed profiles as well as profiles made from two shell parts welded together or InnForm T³. Figure 9 shows the manufacturing steps of the Form-Blow hardening process in principle. These profiles are heated up to austenitization temperature within a furnace and fed into an ACCRA forming tool by a robot. In this temperature condition the parts are shown in "red" in Figure 9. By closing the tool via press stroke the profile bar is formed into the three dimensional stake designs. Sealing elements close the profile on both sides. In difference to the Form-Fixture Hardening, the Form-Blow hardening charges the component with air pressure and shapes it into the final geometry. After the forming process the component is directly quenched with water through the sealing elements. This prompt cooling system leads to a very quick and homogenous decrease of temperature and therefore to a high process stability. The mechanical characteristics and dimensional tolerances of the finished component are comparable to press hardened components. For more details see [4].