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Reliably processable steel for chassis components with high structural durability

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1. Introduction

The demands on suspension components for their safety standards over the entire vehicle life are paramount. This requires completely trouble-free production processes in the forming of the individual parts and their subsequent assembly, including the joining operations. This report introduces a steel, which sustains most complicated deformation processes and ensures high component durability. In as-annealed delivery state, blanks of such kind of steel can be excellently formed into highly complex components using deep drawing or other modern forming techniques. As welded pipe, the steel can be formed with hydroforming processes without intermediate annealing. With a subsequent heat treatment, tensile strength levels of more than 800 MPa can be achieved. The new steel grade found its first industrial application in the integral support member of the new Mercedes-Benz E-Class. Due to the combination of high strength and ductility of the steel, the integral support member has a high capacity to absorb energy during a crash and yet remains insensitive to the occurring high operating loads.

2. Requirements of structural components and their materials

For structural components in the automotive industry there are high demands in terms of safety, weight reduction and cost optimisation.
The choice of a suitable material or material combination aims at attaining:

- high crash and durability requirements
- good formability
- good weldability
- and the applicability of all conventional coating methods for corrosion protection.

From those high-strength steels and lightweight materials already available on the market, it requires to make the right selection, or to develop new composites.
In the case of the integral support of the new Mercedes-Benz E-Class, the required criteria were achieved by choosing a very strong, yet ductile steel.
On the described integral support, the front axle components, steering gear, engine and transmission are mounted. The integral support made of high-strength steel is fixed to the side rails bolted to the body, so it also serves as an important element of the front crash structure of the new E-Class. In case of a front impact, the integral support yields a separate load path on which the impact energy is absorbed selectively. The load paths are shown in colour in Figure 2.1 [1].
The whole material concept of the new E-Class Mercedes-Benz is based on a specific material selection that meets the particular requirements of the structural component (Figure 2.2).

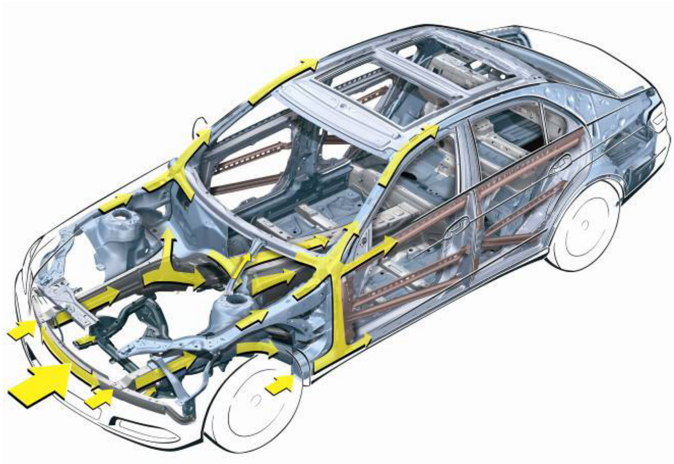


Figure 2.1: Load paths during front-end crash

The selection of a suitable material or composite material significantly reduces the material and production costs. The cost of rework is reduced effectively.

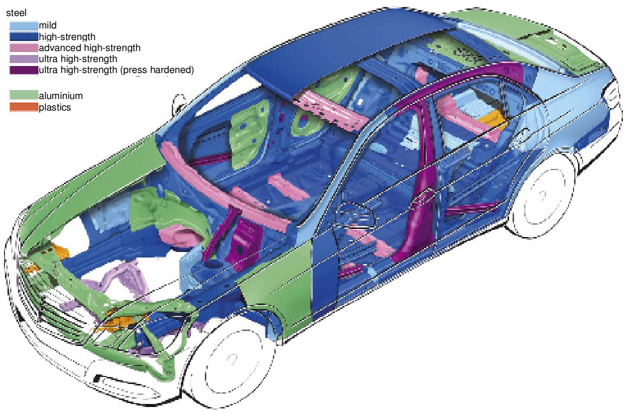


Figure 2.2: Material concept Mercedes-Benz E-Class

3. *Development and production of steel*

The development of suitable chemical composition for the steel was greatly influenced by the demands for the best possible weldability. This firstly refers to the necessary welding processes for the manufacture of welded tubes (laser welding or HF induction welding process). Further, the necessary joining processes during the assembly (MAG welding) of components had to be taken into account. In particular, hardening or softening processes must be avoided. Since the occurrence of chromium carbide precipitations in the welds has a lasting adverse effect on the durability, therefore special attention was paid to this fact. The stated goal was to minimize or completely avoid subsequent tempering treatments.
Experience has shown that with an improved material sturdiness, the measures for reworking are nearly vanished, and subsequent (stress-free) annealing of joined components can be omitted.

In the identification phase for the steel composition further considerations were made concerning the suitability for galvanising.
The two modifications of the steel developed under these preconditions are characterized by the chemical compositions listed in Table 3.1. The differences between steel variants A and B and the resulting characteristics of their properties will be discussed in the following sections. The steel variant A is aimed at a minimum tensile strength after air hardening (LH) and a possible tempering of 800 MPa, variant B of a minimum tensile strength of 900 MPa.

Variant	C	Si	Mn	Cr	Mo	V	B
A	< 0.12	0.2	2.0	0.7	0.2	0.08	0.004
B	< 0.12	0.2	2.0	0.7	0.5	0.15	0.004

Table 3.1: Steel composition (Wt.-%)

The steel is produced in a basic oxygen steelmaking plant and cast on a continuous slab casting machine. After hot rolling, cooling and pickling other process steps may follow depending on the purpose, which are summarized in Table 3.2. The final properties assigned to the respective products will be described later.

Manufacturing options	Process steps						Product
A	Pickling						Hot rolled strip "hard"
B	Pickling		Soft annealing	Temper rolling			Hot rolled strip "soft"
C	Pickling	Cold rolling	Batch annealing	Temper rolling			Cold rolled strip
D	Pickling	Cold rolling	Batch annealing	Temper rolling	Tube welding		Welded cold sized tube
E	Pickling				Tube welding	Tube drawing	Cold-drawn precision tube

Table 3.2: Processing options

All dimensions required for the automotive industry are available. The expansion of the application to truck and trailer manufacturing is obvious.

4. *Material properties*

In Figure 4.1 the YS – T.El value range for cold-rolled air-hardenable steels is inserted in the well-known plot of the cold-formable steels.

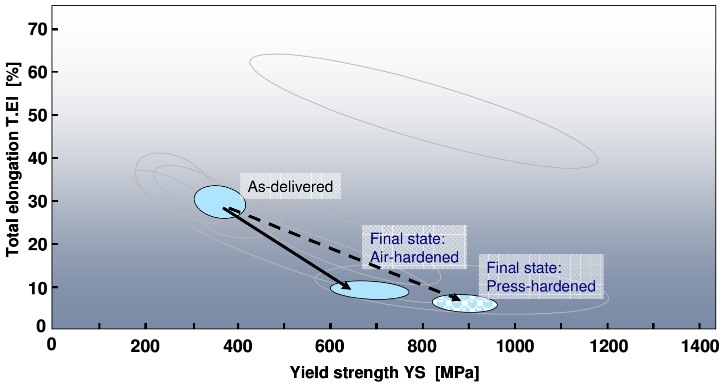


Figure 4.1: Total elongation T.El vs. YS for LH steels in the context of known steels for cold forming

The guaranteed tensile properties in delivery condition of hot and cold strip are given in Table 4.1 for LH steel variant A.

Product	Tensile properties longitudinal
cold-rolled strip	
YS [MPa]	290 - 420
TS [MPa]	450 - 580
U.El [%]	≥ 14
T.El [%]	≥ 25
n value	≥ 0.14

Product	Tensile properties longitudinal
hot-rolled strip "soft" (annealed)	
YS [MPa]	260 - 400
TS [MPa]	460 - 650
T.El [%]	≥ 25
hot-rolled strip "hard" (as-rolled)	
YS [MPa]	800 - 1050
TS [MPa]	900 - 1150
T.El [%]	≥ 9

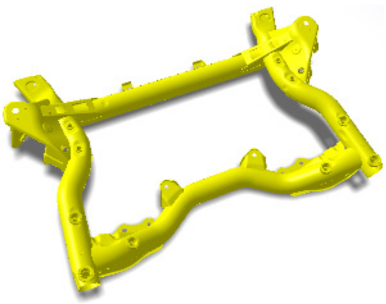
remarks: YS – yield strength
TS – tensile strength
T.El – total elongation with 50mm gauge length

Table 4.1: Guaranteed mechanical properties of LH steel variant A (tensile test on longitudinal samples)

In the order of the intended processing steps, the material was tested for its suitability, set in relation to other cold-rolled steels and evaluated completely (formability, joinability, fatigue strength). Strength-related flow and forming limit curves showed not only an unusual degree of strengthening potential, but also a remarkable forming limit reserve. Attempts to determine the limiting drawing ratio, the Erichsen cupping and the suitability for hydroforming of welded tubes (internal pressure burst tests) completed the material assessment procedure.
In the material selection process, forming limit curves and fatigue strength behaviour of joined specimens were analysed. While being located in the same group as the DP-steel or micro-alloyed steel in terms of the forming potential, the fatigue strength the LH steel features a maximum number of cycles 3 times higher.

5. Integral support of E-Class as an example of application

The E-Class integral support was designed as a welded pipe construction using hydroformed tubes made of laser-welded single tubes, formed metal parts and bulk formed parts (Figure 5.1). The total weight of the uncoated component is 11.7 kg.



Tube formed assemblies (4)	5.6 kg
Sheet metal parts (20)	3.8 kg
Bulk formed parts (10)	1.6 kg
Filler metal	0.7 kg
Total weight	11.7 kg

Figure 5.1: E-Class integral support

As part of the material validation, a new evaluation method of sheet metal formability has been developed in order to obtain reliable data regarding the potential for serial use in terms of forming and separation technology in an early stage of development. The air-hardenable steel shows excellent formability in this new evaluation method offering advantages in some metal forming criteria compared to other steel grades used for formed parts (Figure 5.2).

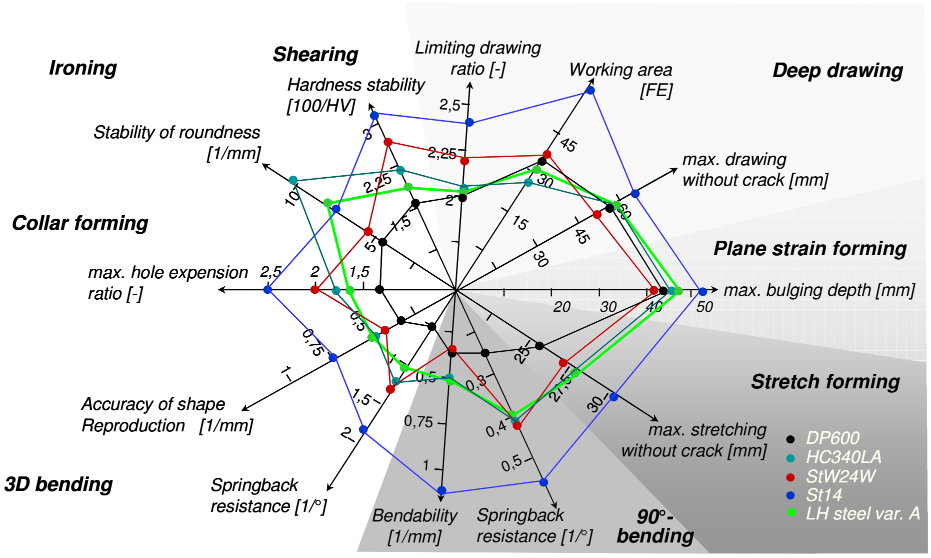


Figure 5.2: Forming and separation technology assessment of air-hardenable steel (variant A) in comparison to other steels

One of the manufacturing challenges lays in the forming of the tube formed assemblies for the longitudinal beam with S-lay. The process steps in forming consist of bending, preforming and hydroforming (Figure 5.3). The excellent formability of the air-hardenable steel in the soft delivery state allowed in conjunction with laser-welded single tubes a robust forming process without the need for an intermediate annealing.

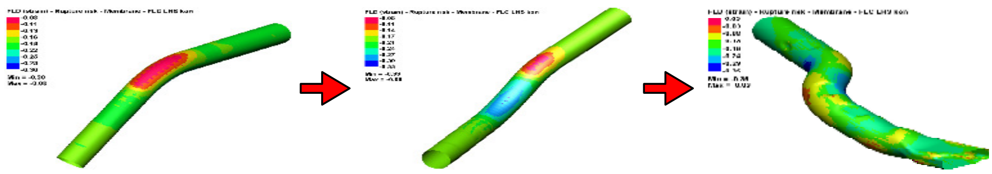


Figure 5.3: Process steps of forming the longitudinal beam with S-lay consisting of bending, preforming and hydroforming

6. Potential of the steel for quenching and tempering

6.1 Effects on microstructure and mechanical properties

The description of the steel by means of TTT diagram (Figure 6.1) reveals that it is heat treatable with lowest cooling gradients.

In soft-annealed condition the steel has a ferritic microstructure, which differs only marginally depending on its pre-treatment (hot-rolled or cold-rolled). Due to the cooling conditions after hot rolling, in the non-annealed hot strip the microstructure is predominantly bainitic with some martensite (see Figure 6.2 top row).

The bottom row of Figure 6.2 shows the microstructures of the hardened steel. They were made on samples after air hardening according to the temperature cycle shown in Figure 6.1.

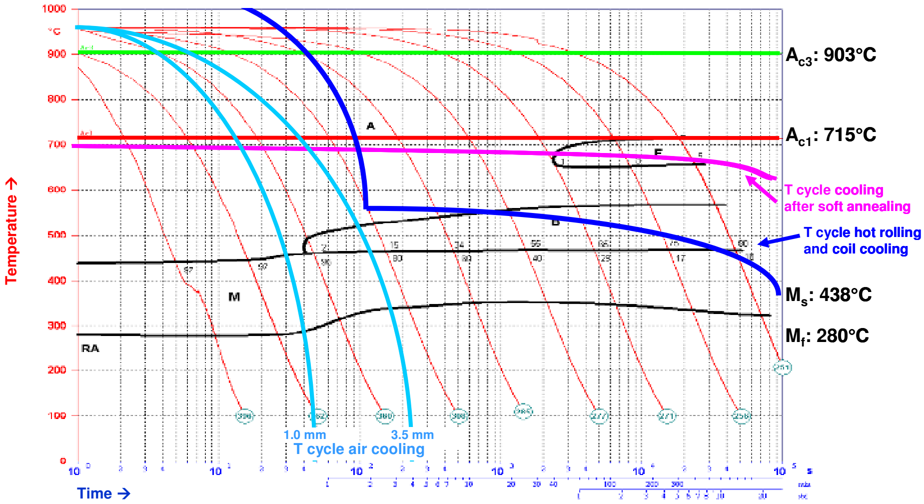


Figure 6.1: TTT diagram of LH steel variant A

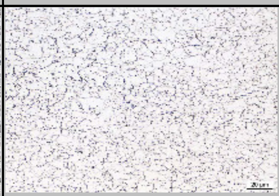
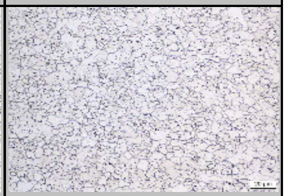
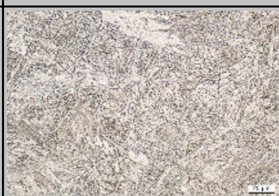
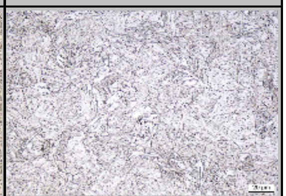
	Hot-rolled as-rolled	Hot-rolled annealed	Cold-rolled
As-delivered	 **3.5 mm** **B 90%, M 10%** 500 : 1	 **3.5 mm** **100% F with globular cementite** 500 : 1	 **1.3 mm** **100% F with globular cementite** 500 : 1
Hardened	 **3.5 mm** **M 100%** 500 : 1	 **3.5 mm** **M 85%, B 15%** 500 : 1	 **1.3 mm** **M 100%** 500 : 1

Figure 6.2: Microstructures of different material states of LH steel variant A

The relation between cooling gradient and the strength values TS and YS is presented in Figure 6.3. The given cooling gradients comprise, i.a., the cooling

conditions in still air and in press hardening. Further, this figure also shows the influence of the sheet thickness at the same kind of cooling.
A tensile strength of 800 MPa is safely achieved with this steel after appropriate air hardening (and possibly subsequent tempering).

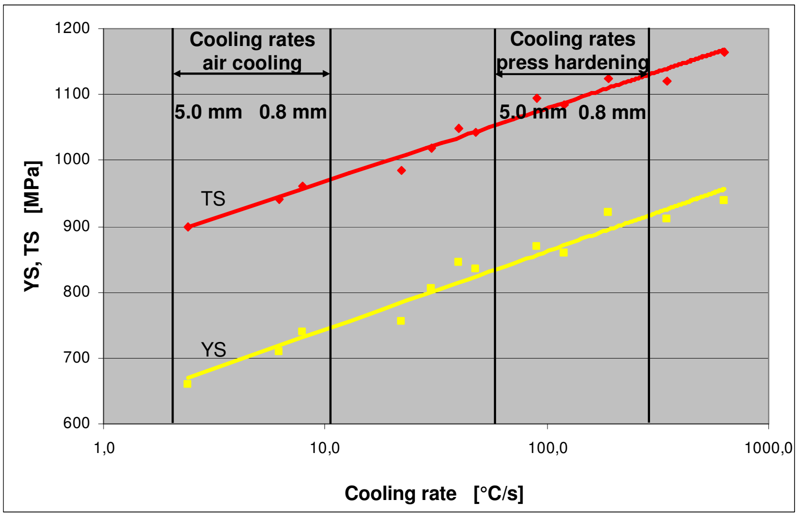


Figure 6.3: Effect of cooling conditions on tensile strength and yield strength of LH steel variant A

6.2 Application example air hardening

The typical air hardening heat treatment consists of an austenization treatment that can last, depending on thickness and shape of the previously cold-formed component (also hydroformed), up to 15 minutes at 930-950°C followed by cooling in still air or in inert gas. If necessary, a tempering treatment for 10-15 minutes at 450-600°C can follow. The manufacturer shall determine the proper final treatment conditions with regard to the required characteristics of the component. To minimize the shape distortion, the optimal component positioning both in the oven and during cooling has to be found through experimentation and by practical experience. Where appropriate, it is advantageous to fix the component during heat treatment. Also, by appropriate design of the component shape the shape distortion can be minimized. Especially closed sections, especially hydroformed components prove to show very low distortion.

Due to the good tempering resistance, surface coating measures including heat treatment, e.g. galvanizing, may be applied. Figure 6.4 shows schematically a corresponding sequence of possible process steps.

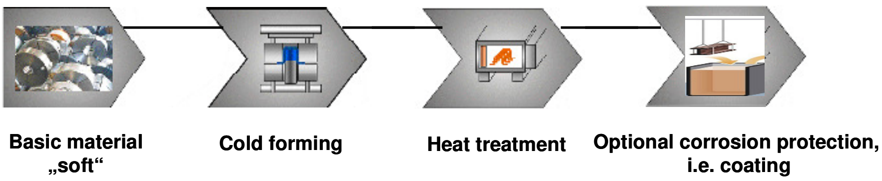


Figure 6.4: Process steps for the production of air-hardened components

As an example of the effectiveness of this option, a comparison of experimentally produced hydroformed B-pillar made of S235JR (2.0 x Ø108 pipe) or air-hardenable steel of variant A (1.8 x Ø108 pipe) was made. The analysis of drop weight tests showed higher performance of the lighter-weight LH steel variant A regarding both the force vs. displacement and in the energy absorption vs. displacement curves (see Figure 6.5)

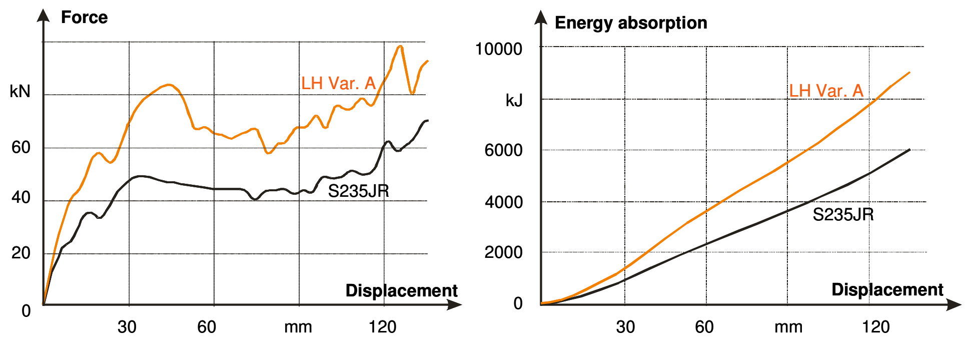


Figure 6.5: Force-Displacement-behaviour und Energy-Displacement-behaviour of hydroformed B-pillars made of S235JR (2.0 mmt) und LH steel variant A (1.8 mmt)

6.3 Application example press hardening

A further increase in strength is possible when sheets or tubes of LH steel Variant A are processed by press hardening. Table 6.1 summarizes the mechanical properties for air hardening (column 2) and press hardening (column 3), and compares them with the properties of a common press hardening steel 22MnB5 after press hardening (column 4).

Mechanical properties			
	Variant A LH Route	Variant A PH Route	22MnB5 PH Route
YS [MPa]	600 - 750	830 - 930	1000 - 1250
TS [MPa]	900 - 1000	1050 - 1200	1300 - 1650
T.El [%]	11 - 16	9 -14	6 - 9

Properties vary depending on temperature cycle during hardening

Table 6.1: LH steel variant A after air hardening (LH route) and press hardening (PH route) in comparison to 22MnB5 after press hardening

It should be noted that while the tensile strength of LH steel variant A is 250 to 450 MPa lower in comparison to 22MnB5 after similar treatment (PH-route), the total elongation is actually 3% higher. The advantage in the case of extreme component load (crash) is obvious.

The softening of the press-hardened component in the heat affected zones in the case of LH steel is limited to the strength level, which is typical for the air hardening route.

According to a report by F. Schieck on research at the Fraunhofer Institute [2], a combined hydroforming press-hardening process using tubes of LH steel Variant A was successfully realized. The mechanical properties after press hardening are in

accordance with the data given in Table 6.1. A subsequent tempering confirmed the mentioned tendencies.
Especially if applying the so-called 2-stage press hardening process (cold preforming of the blanks followed by final shaping by press hardening), the excellent cold formability of the LH-steel can be utilised.

6.4 Local inductive hardening

Induction hardening was previously the domain of massive components made of classic Q&T steels such as wheel carriers, side shafts, etc. By using the air hardenable steel, an induction hardening of localized component regions is now possible even for thin-walled sheet metal weldments. In structural components, this results in new possibilities for component design with respect to strength and crash characteristics [3]. In the case of sheet metal parts there are two possibilities of manufacturing. Either the individual components are hardened locally by feed or shot hardening and then welded together in the assembly, or the parts that have to be locally hardened can be induction hardened by shot hardening after the assembly (see Figure 6.6).

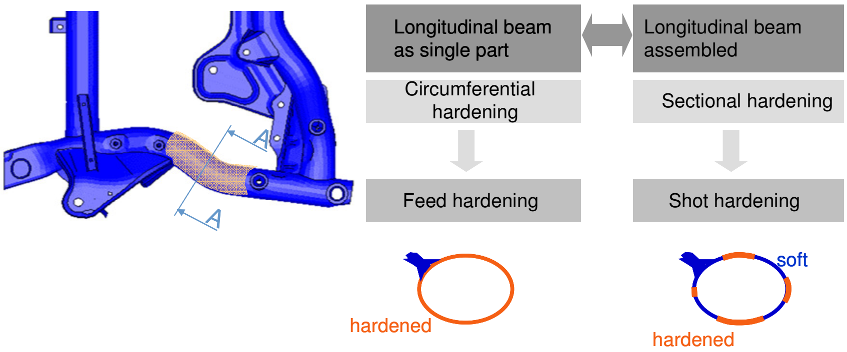


Figure 6.6: Local induction hardening of sheet metal weldments on the example of E-Class integral support via feed and shot hardening

- full section completely hardened (orange)
- section with striped hardening, hardened (orange) - soft (blue)

Figure 6.7: Feed hardening of a girder in a MF vertical hardening system (300kW, 8-10 kHz) for induction hardening

Because of air hardenability, there is no need for quenchants in the induction hardening of LH steel variant A. The surface can be protected from scaling by an inert gas. Using appropriate parameters, the same mechanical properties are reached as in the hardening furnace. After hardening, the ductility of locally induction-hardened areas of the component can be raised by a tempering heat treatment, either locally or of the whole component. Figure 6.7 shows a corresponding system for the feed hardening.

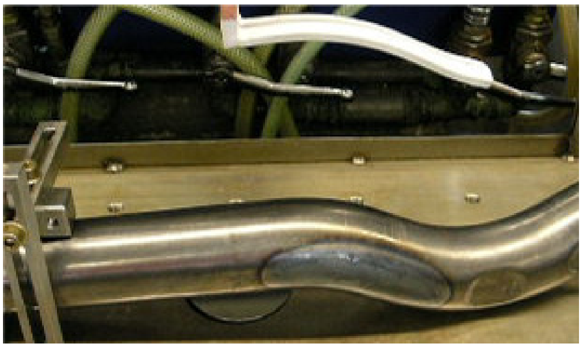


Figure 6.8: Longitudinal girder in the area of the S-lay after single part shot hardening

In trials on longitudinal girder prototype parts (Figure 6.8) of the E-Class integral support, part distortion was tolerable at max. 0.6 mm.

7. Conclusion

Development and properties of a new air-hardenable steel are described. The initially planned use in the component sector was implemented successfully. Its processing is virtually free of rework. Corresponding components or elements have a disproportionate fatigue strength and also contribute to reduce the weight of the vehicles. The (air) hardening of complete components made of the developed steel can be extended to local areas of the component and the use of the steel for press hardening in conjunction with a hot stamping process. Further, the press hardening associated with hydroforming has been tested. After press hardening, crash-relevant residual strains on the component are realised.

The presented examples and components show the advantageous effects achieved with new air hardening steels, and what potential can be tapped in their extensive use.

Literature

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