Application of air-hardening steels for highly stressed structural parts with simplified heat treatment

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Summary

Lightweight design is one of the central topics for the future of the automotive industry. The usage of air-hardening steels in manufacturing of cars and trucks can lead to significant weight reduction. These high-strength steel grades sustain most complicated deformation processes and ensure high component durability. In the soft delivery state, the blanks can be excellently formed into highly complex components using deep drawing or other modern forming techniques. As a welded pipe, the steel can be formed using hydroforming processes without intermediate annealing. With a subsequent heat treatment, tensile strength levels higher than 800 MPa can be achieved. In this case, the components are heat-treated after forming under a protective gas atmosphere and finally hardened with natural cooling in air or inert gas. Thanks 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. The selected air-hardening steel was first used in the integral support BR212 of the current Mercedes E-class. While in this case the steel remained in the soft state, the air-hardening potential of the selected steel grade is now fully utilized in the longitudinal beams of the integral support member of the new Mercedes-Benz C-Class, in order to meet the increased demands on structural durability and crash performance requirements. In particular, the advantages of the material concept of air-hardening steels come to fruition in local strengthening of such component parts that are exposed to higher loads. Due to the specific steel composition, the conditions of quenching and tempering treatment were simplified. The tempering of the longitudinal beams that are air-hardened in a continuous furnace is now carried out during the baking treatment of the cathodic dip coating of the welded assembly.

Keywords

Air-hardening steel, lightweight construction, high strength steel, heat treatable steel, hardenability, tempering

Introduction

The central challenge for every automaker is currently, and will be in the future, the implementation of measures for the reduction of CO2 emissions of the vehicles. Particular attention must be paid to the fact, that this requirement applies to both the production (including production of the materials used) as well as for operation and recycling of vehicles. At the same time, new cars have very high requirements (partly due to changed legal situations) with respect to their quality and production safety, rigidity and crash performance. The trend towards lightweight construction is becoming the key development strategy, from an ecological perspective, for new generations of vehicles. Functionality and minimal production costs are only accessible when the potentials of the steel as the construction material of choice, a load-optimized design of the components and the application of rationalized production processes are subjected to a holistic process. The development of new steels and methods of processing plays a key role.

Demands on suspension components and materials to be used

For structural components in the automotive industry there are high demands in terms of safety, weight reduction and cost optimization. In integral support members with steel design, Mercedes-Benz has made very good experiences with air-hardening steel (LH) in the current model of the E-Class.
On such integral support, the front axle components, steering gear, engine and transmission are mounted. The integral support is fixed to the side rails bolted to the body, so it also serves as an important element of the front crash structure. In case of a front impact, the integral support provides a separate load path on which the impact energy is absorbed selectively.

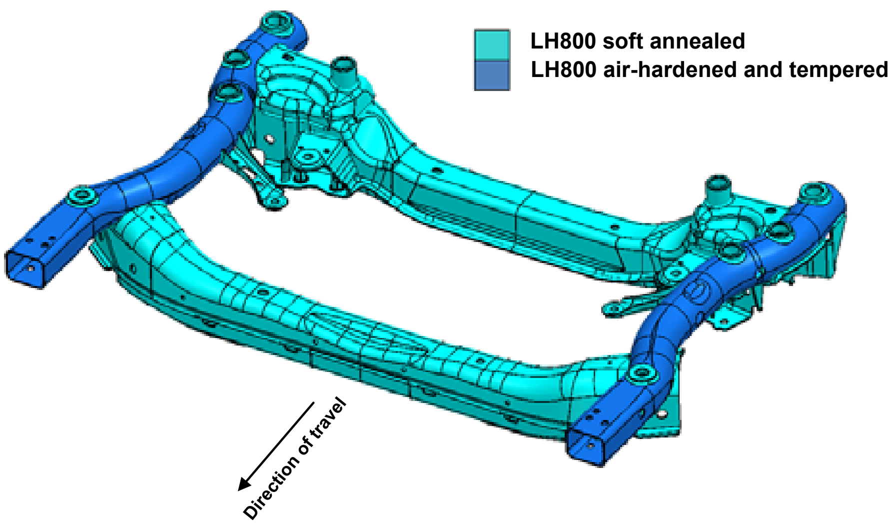

Fig. 1: CAD image of the integral support with air-hardened and tempered longitudinal beams

So far, the use of air-hardening steel in the soft (annealed) state was the right solution to meet the strength and crash requirements. Taking into account the increased demands of the new C-Class, the crash relevant longitudinal beams in the integral support are now used in the air-hardened and tempered state (Figure 1).

Published: International Conference on Steels in Cars and Trucks, June 15-19, 2014, Braunschweig; © 2019 Steel Institute VDEh

Thereby, in the case of a frontal crash, the force level of the integral support is increased at an early stage (Figure 2).

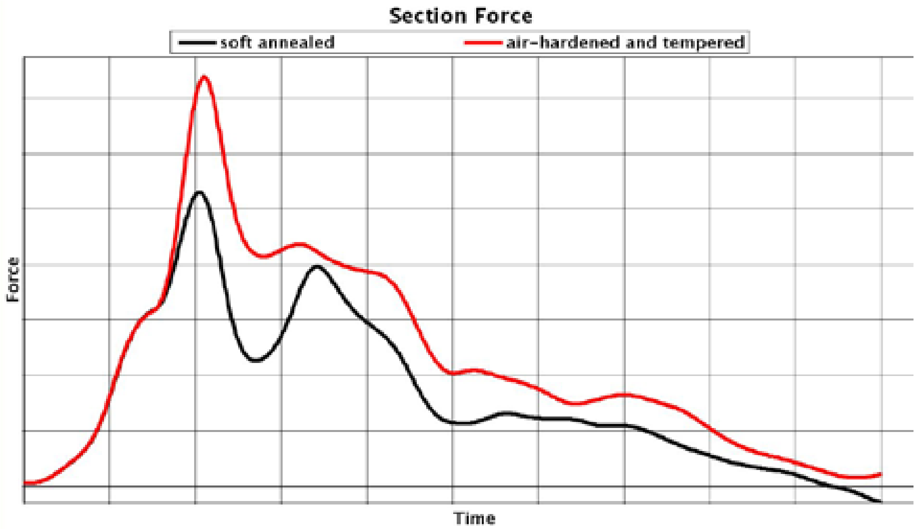

Fig. 2: Deformation of the longitudinal beam

High strength components and elements made of LH steels ensure the greatest possible passenger protection at high static and dynamic loads, both during normal vehicle operation and in the event of a crash. These steels are therefore modern alternatives to high and ultra high strength steels, especially in manufacturing complex components and shapes which require both a high degree of formability and highest strength. In comparison to such steel grades, air-hardening steels deliver much higher strengths, and even outperform aluminum and other light metal alloys in this respect. As a result, the plate thickness can be reduced considerably. Another advantage of LH steels is the outstanding structural durability compared to alternative high-strength steels [1]. This means that LH steels fulfill the current requirements for automotive materials in terms of both safety requirements and lightweight construction potential.

Material properties in the delivery state and in the final component

In their soft delivery state, cold-rolled air-hardening steels show excellent formability properties. They are well suited for the production of laser or HF-welded tubes, which can be further processed by bending or hydroforming without intermediate annealing [2]. When heating the cold formed components to hardening temperature and then cooling them with moderate cooling rates, corresponding to cooling in calm air, distortion-free high-strength parts can be manufactured. Even after a possible tempering treatment high tensile strength values up to 1000 MPa remain. The joining of the formed parts made of this steel using resistance spot welding, laser or MAG welding is user-friendly.

C	Si	Mn	Ti	Cr	B	Mo	V
< 0.12	0.25	2.0	0.03	0.8	0.003	0.25	0.07

Tab. 1: Steel composition of LH800 (wt.-%)

The steel applied to manufacture the integral support presented here has a minimum tensile strength of 800 MPa in the air-hardened and tempered state, hence the designation LH800 is subsequently used. The typical chemical composition of the steel is given in Table 1.
The guaranteed tensile properties in delivery condition of hot and cold strip are given in Table 2. The common delivery state of hot- or cold rolled strip or sheet is "soft" (annealed). In this state, the material shows excellent formability offering advantages in some metal forming criteria compared to other steel grades used for formed parts [2]. For special purposes, the hot strip can be delivered in the state "as rolled".

Product type	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 type	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]	600-1050
TS [MPa]	750-1150
T.El [%]	≥ 9

remarks: YS - yield strength
TS - tensile strength
U.El - uniform elongation
T.El - total elongation A_{80} (cold-rolled) or A_5 (hot-rolled)

Tab. 2: Mechanical properties of LH800 (tensile test on longitudinal direction)

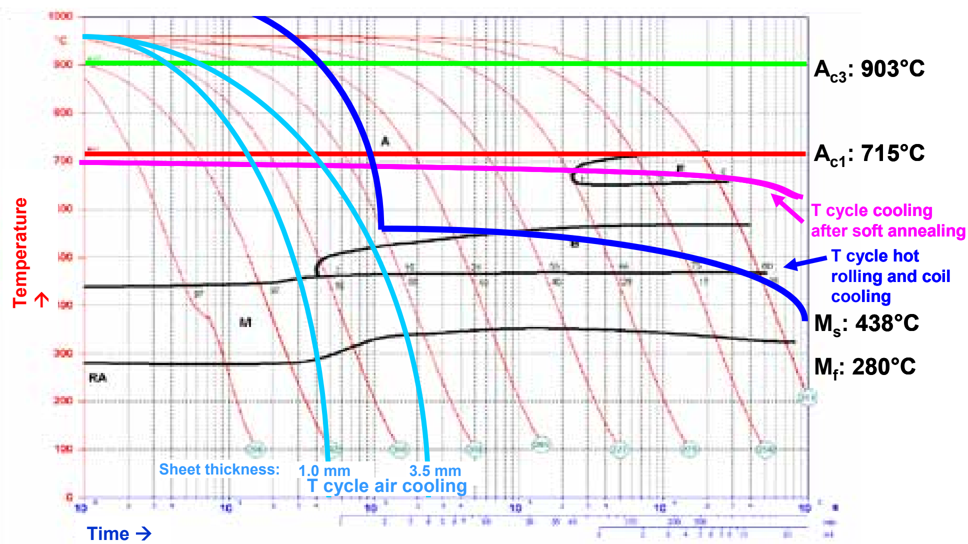

Fig. 3: TTT diagram of LH800

The LH steels are classified as so-called PFHT steels (post-forming heat-treatable). Consequently, the formed elements can be heated in the furnace in a downstream manufacturing process that uses a protective gas, and then tempered

by means of natural cooling in air or a protective gas. The description of the steel by means of TTT diagram (Figure 3) reveals that it is heat treatable with lowest cooling gradients.
The typical air hardening heat treatment consists of an austenitization treatment that can last, depending on thickness and shape of the previously cold-formed component, up to 15 minutes at 900-930°C followed by cooling in calm air or inert gas. Higher austenitizing temperatures may result in significant grain growth of the austenite grains. For this reason, heat treatment at temperatures above 950°C is not beneficial regarding mechanical properties [3]. The other hand, especially at small sheet thicknesses, the hold time in the austenitizing furnace can be reduced to 4-6 minutes, which leads to significantly reduced cycle times in production.

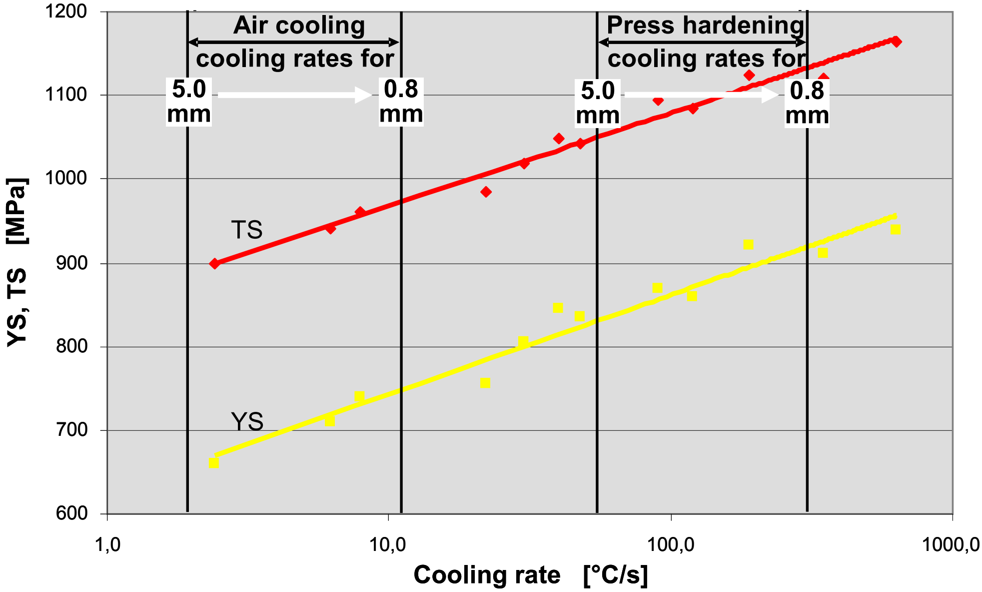

Figure 4: Effect of cooling conditions and sheet thickness on tensile strength and yield strength of LH800 after austenitizing at 930°C for 15 min.

The relation between cooling gradient and the strength values TS and YS is presented in Figure 4. The given cooling gradients comprise, in particular, the cooling conditions in calm 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). A further increase in strength is possible when sheets or tubes of LH800 are processed by press hardening. According to a report of the Fraunhofer Institute [4], a combined hydroforming press-hardening process using tubes of LH800 was successfully realized.
If necessary, the hardening may be followed by a tempering treatment. By variation of the processing parameters (annealing temperature and holding time), the desired mechanical properties can be adjusted. The effect of the tempering treatment on the mechanical properties of air-hardened LH800 is shown in Figure 5. The results show that tempering temperatures of about 300°C should be avoided because temper embrittlement may occur, to some extent. Otherwise, a cathodic dip-paint coating treatment at 180°C with holding times of 30 minutes is

sufficient to reach the desired tempering effect on the mechanical properties. This treatment results in a pronounced bake-hardening effect, with increases in both yield strength and tensile strength. In addition, the scattering of the mechanical properties gets significantly lower. At these low tempering temperatures of under 200°C, carbon diffusion processes towards lattice defects and cluster formation occurs, accompanied by precipitation of small iron carbides leading to strength increase due to dislocation pinning and precipitation hardening [5].

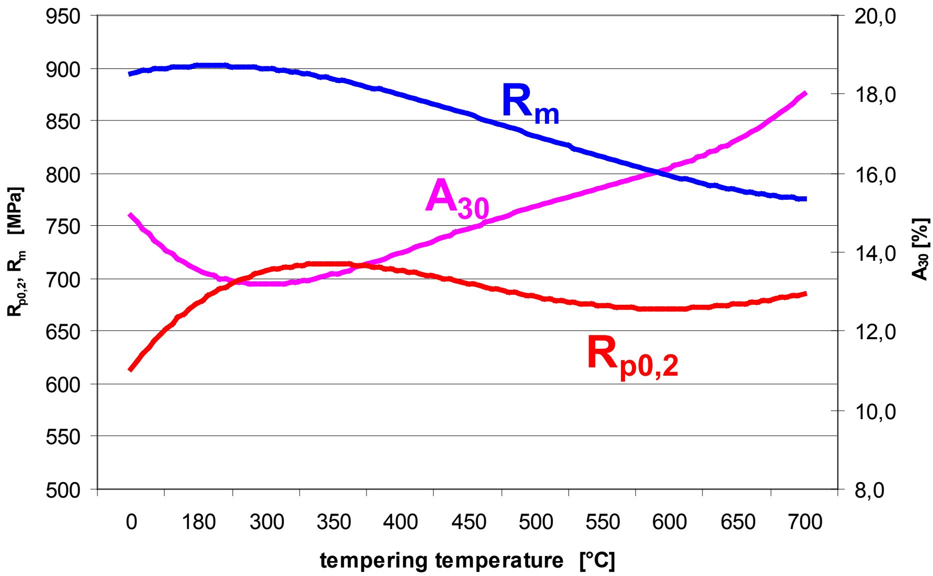

Fig. 5: Effect of tempering temperature on mechanical properties of LH800 (holding time 25 min)

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 worked out on the real part. Where appropriate, it is advantageous to clamp the component during heat treatment. Also, by appropriate design of the component the shape distortion can be minimized.

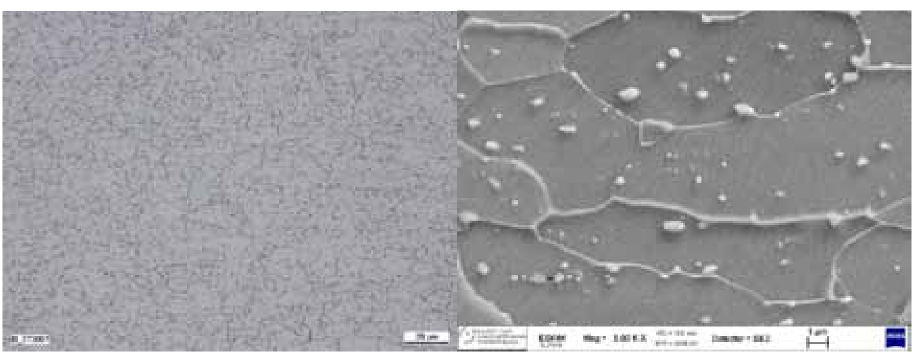

Fig. 6: Microstructure of LH800 in soft (annealed) delivery condition

In soft-annealed condition the steel has a ferritic microstructure, with small and evenly distributed precipitates of carbides and carbonitrides of the types $(Cr,Mo)_xC$ and V(N,C) (see Figure 6). The microstructure of the air-hardened steel is mainly composed of martensite or mixtures of martensite and bainite, with small precipitates which form and size depends on the heat treatment conditions (see Figure 7).

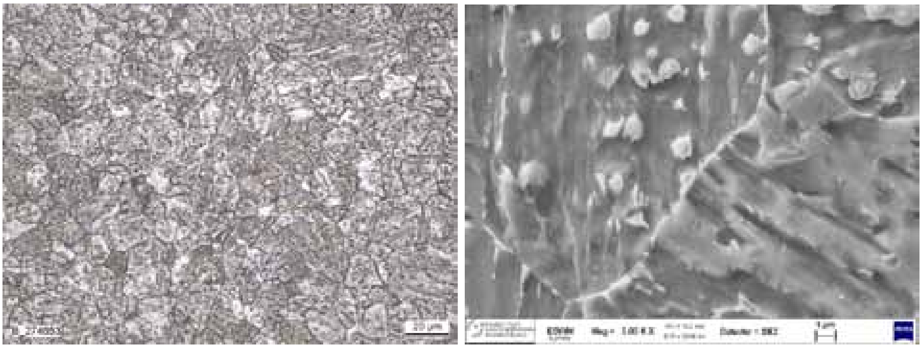

Fig. 7: Microstructure of LH800 in the air-hardened condition

Performance example integral support of the new C-Class

The integral support of the new C-Class was designed as a welded construction made of pipe and sheet parts. The schematic fabrication sequence of the integral support is shown in Figure 8.

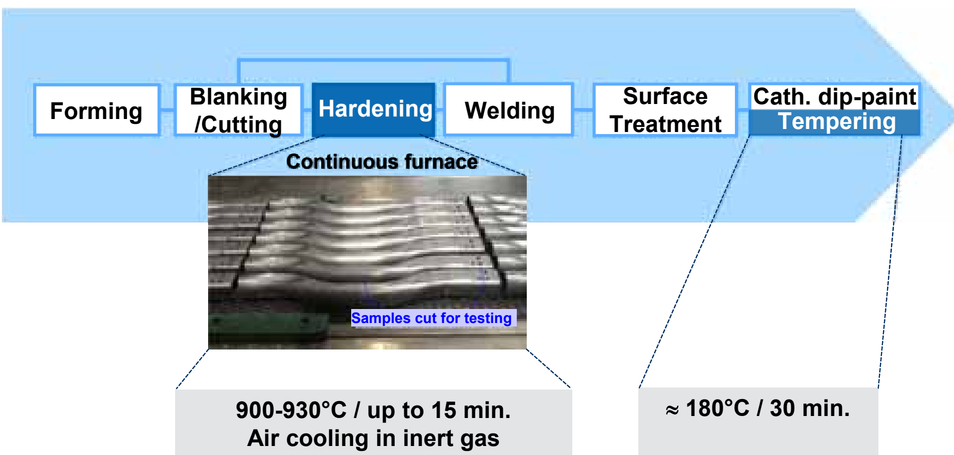

Fig. 8: Schematic manufacturing sequence of the integral support of the new C-Class

For the longitudinal beams, single tubes made of air-hardening steel are used. After bending and embossing, the longitudinal beams are heat treated in a continuous furnace under a protective gas. After air hardening, the parts show low distortion and can be welded during the assembly without additional straightening. The cross members are designed as a sheet metal shell construction, using tailored blanks for the upper sheet metal shells made of air-hardening steel. The total weight of the finished coated component is 12.95 kg.

The integral support is thick film-CDP (cathodic dip-paint) coated. Through the paint baking during the CDP process, the air-hardened longitudinal beams of the welded assembly undergo a tempering treatment. Compared to a conventional heat treatment consisting of hardening and subsequent tempering of the parts, in this case an additional heat treatment step is avoided.

Other possible applications of air-hardening steels

The good experiences with the application of LH800, either during processing as well as in the loaded components, have prompted car manufacturers to explore other possible applications for the air hardening steels. These are in particular such welded components which are subjected to high static and dynamic loads, and have load-bearing and safety-related functions, such as drive shafts, hybrid handlebars, wishbones, roll bar or trailer axles. This gives the car manufacturers new opportunities to further reduce vehicle weight, what ultimately contributes to resource conservation and reduction of pollutant emissions.

Conclusions

Air-hardening steels sustain most complicated deformation processes and ensure high component durability. The air-hardening potential of LH800 is fully utilized in the longitudinal beams of the integral support member of the new Mercedes-Benz C-Class, in order to meet the increased demands on structural durability and crash performance requirements. In particular, the advantages of the material concept of air-hardening steels come to fruition in local strengthening of such component parts that are exposed to higher loads. Due to the specific steel composition, the conditions of quenching and tempering treatment were simplified. The tempering of the longitudinal beams that are classically hardened in a continuous furnace is now carried out during the baking treatment of the cathodic dip coating of the welded assembly.

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