SALZ

MAGAZINE FOR STRIP STEEL

No. 8

xpand®

SALZGITTER FLACHSTAHL

A Member of the Salzgitter Group

CONTENTS

Welcome!

Developments in automotive engineering are necessitating the manufacture of increasingly complex component geometries. Salzgitter Flachstahl has continued to develop its multi-phase steels for such critical forming steps. This new generation of multi-phase steels is designated by the name affix xpand®, and we'd like to introduce you to the characteristics of these steel grades as well as the solutions they make possible.

Each component generation is placing ever higher requirements and demands on the mechanical properties of the initial material. It is becoming increasingly necessary to precisely analyze and describe material properties and the processing limits. In serving our customers, we perform a series of test procedures that record this data in a precise manner. You can read about a few of these procedures beginning on page 16.

In this issue of our SAL-Z magazine, we'll also give you a detailed look at how we continue to develop xpand® steels in practice and in close partnership with our long-standing customers, as well as present the advantages offered to both you and our customers as a result of the expertise we've acquired.

I wish you an enjoyable reading.

SALZ

Frank Heidelberger
Head of Marketing at Salzgitter Flachstahl GmbH

KIRCHHOFF AUTOMOTIVE

▲ Kichhoff Automotive GmbH at the Attendorn location

Tradition-based future

Kirchhoff Automotive GmbH, headquartered in Iserlohn, is a fourth-generation family-run automotive supplier. Including the predecessor companies, the entire Kirchhoff Group can look back on a 230-year history.

As a development partner for the automotive industry, today the company manufactures complex metal and hybrid structures for the body-in-white and chassis. In 2013, the Group generated sales of EUR 1,190 billion and employed more than 8,400 employees in 12 countries. Since the takeover of the majority interest in Canadian company Van-Rob, Kirchhoff Automotive boasts 29 production plants located in Europe, Asia and North America. One of the sites is located in Attendorn, in South Westphalia. Kirchhoff Automotive's company-owned Tec-Center emphasizes the development of modern components. Salzgitter Flachstahl supplies South Westphalia with high-strength material, among other things for side impact bars. ◀

TOWER INTERNATIONAL

▲ A view of the Tower International plant in Zwickau

Component know-how worldwide

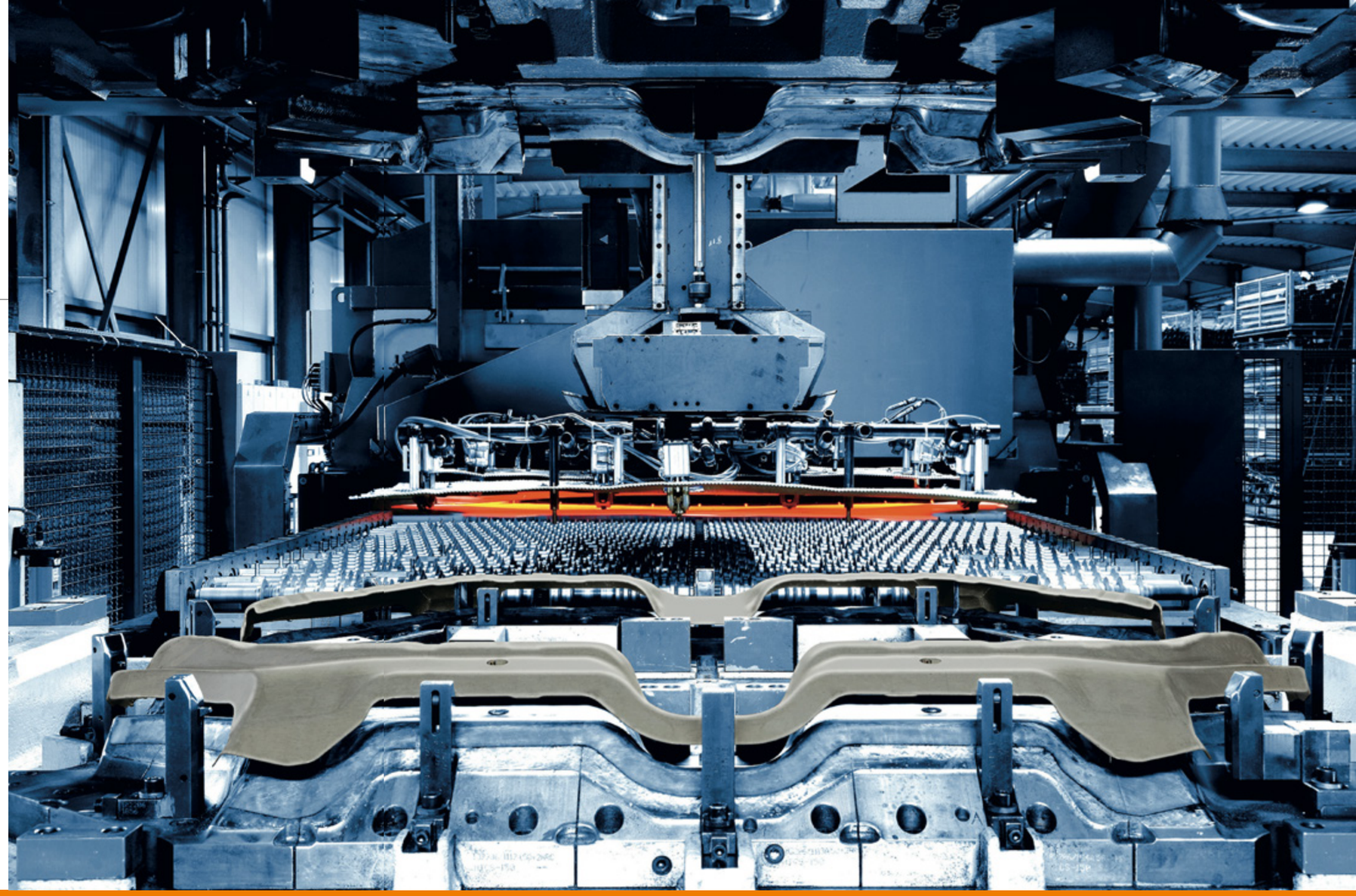
Tower Automotive is one of the world's largest automotive suppliers for stamping parts and body components. The company supplies all major automotive manufacturers, including Porsche, Volkswagen and BMW. Since the turn of the millennium, the modern stamping facility in Zwickau has been manufacturing components for various types of vehicles. Here, a 4,500-ton large-format transfer press - unique in Europe - is at work. 400 employees are active at the site in Saxony, while 8,700 employees are employed in 13 countries worldwide. Together, they generated a total of 2.1 billion US dollars in revenue in 2013. The parent company is based in Livonia, Michigan. Tower Automotive uses steels from Salzgitter for vehicle side members, among other applications. ◀

KIRCHHOFF AUTOMOTIVE

RESEARCH AND DEVELOPMENT FOR THE PRODUCTS OF THE FUTURE

South Westphalia is characterized by a large number of metal processing companies. This is the center of metal forming know-how, where vehicle manufacturers rely on proven and multifaceted expertise. This includes the KIRCHHOFF Group with the KIRCHHOFF Automotive division at the Attendorn site. The company's operations have been up and running in this region for 230 years. Tradition and reliability are the basis for ever new developments in vehicle and chassis construction. Together with Salzgitter Flachstahl, engineers in research and development work on new materials and processes.

Dipl.-Ing. Christoph Wagener
Director of Research & Product Development,
Kirchhoff Automotive GmbH



Core competency press hardening:
Kirchhoff Automotive produces metal and hybrid structures for vehicles

The current starting point for the cooperation was a capability analysis in which a high-strength material for a side intrusion beam was to be determined. The aim was as follows: The component geometry specified was to be designed in a way to render it light and rigid at the same time, with as little deformation as possible when under stress.

"This is our daily task: to meet car manufacturers' requirements with materials available on the market in a manner that is economically viable for all parties involved. In order to achieve this, we need a reliable partner", explains Dipl.-Ing. Christoph Wagener, Head of Research and Product Development at KIRCHHOFF Automotive, regarding the background for cooperation with Salzgitter Flachstahl.

KIRCHHOFF Automotive manufactures metal and hybrid structures for vehicles and covers a wide range of metalworking operations: forming, joining, surface treatment, in-house tool development and the associated logistics for delivery comprise the performance spectrum that meets the market requirements of the automotive industry.

The vehicle manufacturers' requirements are numerous, and are ultimately environmentally driven as well: Suppliers' components need to be as light as possible, in order to reduce or limit fuel consumption through weight savings. On the other hand, they must have a safe structure in order to be able to absorb or redirect impact energy in the event of a crash. This means that ever higher-strength steels are necessary. "Today, we face the challenge of having to implement stable geometries with material thicknesses of less than two millimeters which prevent deformations or ensure optimal energy transfer," says research manager Christoph Wagener in describing the tasks his company faces. "Steel is simply the most cost-effective light-weight solution for this task. Aluminum is comparatively much more costly and is not particularly economically viable." Volkswagen has installed up to 35 press-hardened components in some vehicles – consequently, finding the right steel for the components is enormously important for the development engineers at KIRCHHOFF Automotive.

Christoph Wagener is clear when characterizing the cooperation with Salzgitter Flachstahl: "Simply put, the cooperation is a major benefit for us in that we have the same way of working, the kind of engineering-style thinking when it comes to Salzgitter Flachstahl's application technology." The cooperation has no preconceived notions with regard to the development of new components, as not only is a specific problem being solved, but the foundations are also being laid to derive uses for other applications. "As a supplier, we know the requirements of the market and the products demanded here," says Wagener. "Salzgitter Flachstahl has the quality and grades of steel that meet this, or which even demonstrate new ways of doing things. Together, we're working to meet the demand. ▶

▲ **A sample geometry for the development of a side impact bar:** the material with the designation HCT780XD**xpand®**

◀ Quality steel for different vehicle parts, manufactured with high-tech tools

The results of tests and research are the basis for further product designations".

KIRCHHOFF Automotive has developed its own database, which safeguards the findings gleaned from numerous tests and provides an optimal foundation for new developments. In the specific case of the potential analysis, the first step involved performing a simulation for a sample geometry in order to identify the critical areas on the component.

"We wanted to know where cracks or thickenings occur during the forming process and where the component fails under load," says Christoph Wagener. Salzgitter Flachstahl provided the material for the practical test in the form of HCT780CD xpand®. Kirchhoff Automotive then performed a static three-point bending test with the formed component. "Ideally, no cracks form under load. Safety can only be achieved by means of test series, which we then carried out," explains Wagener regarding subsequent procedures. The result: deformation occurred at the points described in the simulation, the side impact beam absorbed the energy as predicted. "As a supplier that also needs to subsequently manufacture in series, it's important to know if the test can tell us whether crack-free forming can also be achieved for the product manufactured in the normal production process. The series test and the continuous communication with the material experts from Salzgitter Flachstahl form a reliable basis for this." The potential analysis was a success – the side impact bar is ready for series production.

▶ **Forming know-how is typical for the region:** Kirchhoff employees testing components

The development of technical expertise oriented to real market requirements takes place in Attendorn, but not only together with Salzgitter Flachstahl. An in-house Tec Center with more than 100 employees offers its customers the most comprehensive service, from build-to-print to the independently developed products. The complete development chain is present here, from the design concept to finite element calculations and feasibility studies as well as prototype construction with final quality tests and stress tests.

In addition, KIRCHHOFF Automotive is part of a network in the region. The Automotive Center Südwestfalen (ACS) combines the expertise of more than 100 member companies, mainly medium-sized metal processing companies. The members have the opportunity to bring their specialist knowledge into a wider context and to benefit from the experience of others. It's not just about building expertise. Rather, the ACS also offers training opportunities. KIRCHHOFF Automotive is a founding member and partner. The group of partners also includes the University of Siegen and the Fachhochschule Südwestfalen, as well as the district of Olpe and the city of Attendorn. This forms a clear link between the region and the metalworking and metal forming – a link that is also intended to be developed in sustainable manner. The value orientation and the KIRCHHOFF Group's sense of tradition go hand-in-hand with this thinking, seeing how the fourth generation of the Kirchhoff family currently manages the company. "There will also be a fifth-generation Kirchhoff," comments Christoph Wagener regarding the company's succession plan. "This makes it clear that we at KIRCHHOFF Automotive are keeping an eye on the issue of sustainability at many levels, not just in terms of the environment."

Apropos sustainability: KIRCHHOFF Automotive is also increasingly looking to keep an eye on the energy expended in the manufacture of components, right from the very outset. This is not only due to business considerations, but also from an environmental policy perspective.

Christoph Wagener sums up the challenges: "Our goal is to be able to produce as high-strength as possible with cold-forming steels. This can be very well achieved with the steels and grades provided by Salzgitter Flachstahl – and this applies equally to both product quality and profitability". ◀

There's always something in motion at the pressing plant Presswerk Zwickau GmbH from Tower International. Visitors can even literally feel it for themselves once they're in the administration building: six to ten times a minute things shake and you hear a dull rumbling – the neighboring presses are performing their constant work. So right from the start, one senses that a great deal of effort is being made to transform steel.

TOWER INTERNATIONAL

MODERN PRESSING PLANT WITH HISTORY

The plant, which grew out of the former VEB Sachsenring in 1991 and has some 400 employees in Zwickau, belongs to automobile supplier Tower International, which is headquartered in Livonia, Michigan. At a total of 29 locations around the world, Tower Automotive manufactures structural parts and panels as well as complete shell construction, doors and flaps in car body construction. In Zwickau, located in Saxony, for example, parts are manufactured for Volkswagen, Porsche and BMW, and high-strength steels are processed, lately also with the newly added in-house press hardening facility. The European headquarters with Tower Automotive Holding GmbH is based in Cologne, with additional plants located in Germany in Duisburg, Buchholz and Artern. Other plants in Poland, Slovakia, Belgium, Italy and the Czech Republic ensure that Tower International can manufacture where its customers are. In Italy, this ensures that chassis parts can be quickly integrated into the production process for the latest Fiat models. ▶

Unique in Europe: The 4,500 ton transfer press in Zwickau

▲ **Ralf Krähe**
Director Assembly Engineering
Europe Tower Automotive
Holding GmbH

▲ **Bernd Decker**
Vice President Operations Europe
Tower Automotive Stamping Plant
Zwickau GmbH

Bernd Decker, Vice President of Operations Europe (Zwickau) and Managing Director of Tower Automotive Presswerk Zwickau GmbH, and Ralf Krähe, Director Assembly Engineering Europe (Cologne) from Tower Automotive Holding GmbH, use a tour of the plant to explain the multi-ram transfer presses specified for the highest-strength cold-forming steels. “Until 1991, body parts for the Trabant were manufactured in this shop floor. A painting from the seventies in our cafeteria shows very vividly that, at the time, many 500-ton presses and considerably more employees were necessary for production than is the case today,” says Ralf Krähe, touching on the history of the factory. The extent to which production has changed becomes clear when you stand in front of the large 4,500-ton transfer press, which was put into operation in 2006.

“This press is unique in Germany, even in Europe - it is the most modern and powerful of its kind,” explains Bernd Decker. “The highly efficient system is enormously important for us because we can manufacture chassis parts in the numbers and quality required by our customers”. Noting the performance capacity of the presses in Zwickau, Ralf Krähe smiles mischievously and adds: “We can do more than the steel”.

The tool change in the system is possible in less than ten minutes. Given the size of the press and the tools, it seems as fast as a seconds-long pit stop in Formula One. “The speed at which the tool is changed is what saves money and ultimately makes the system profitable,” explains Krähe. In the 3,000-ton press in Malacky, in Slovakia, the tool can even be changed in an average of 4.5 minutes. “Average,” emphasizes Bernd Decker with visible pride.

A tryout press which would be sufficient for many companies as a backbone of their de facto production is used to test the tools in detail in order to avoid the possibility of the big press being stopped for fine tuning when the tools are used in the latter. The trial stampings also ensure that the 4,500-ton press can produce without interruption – because time is money, as everyone knows.

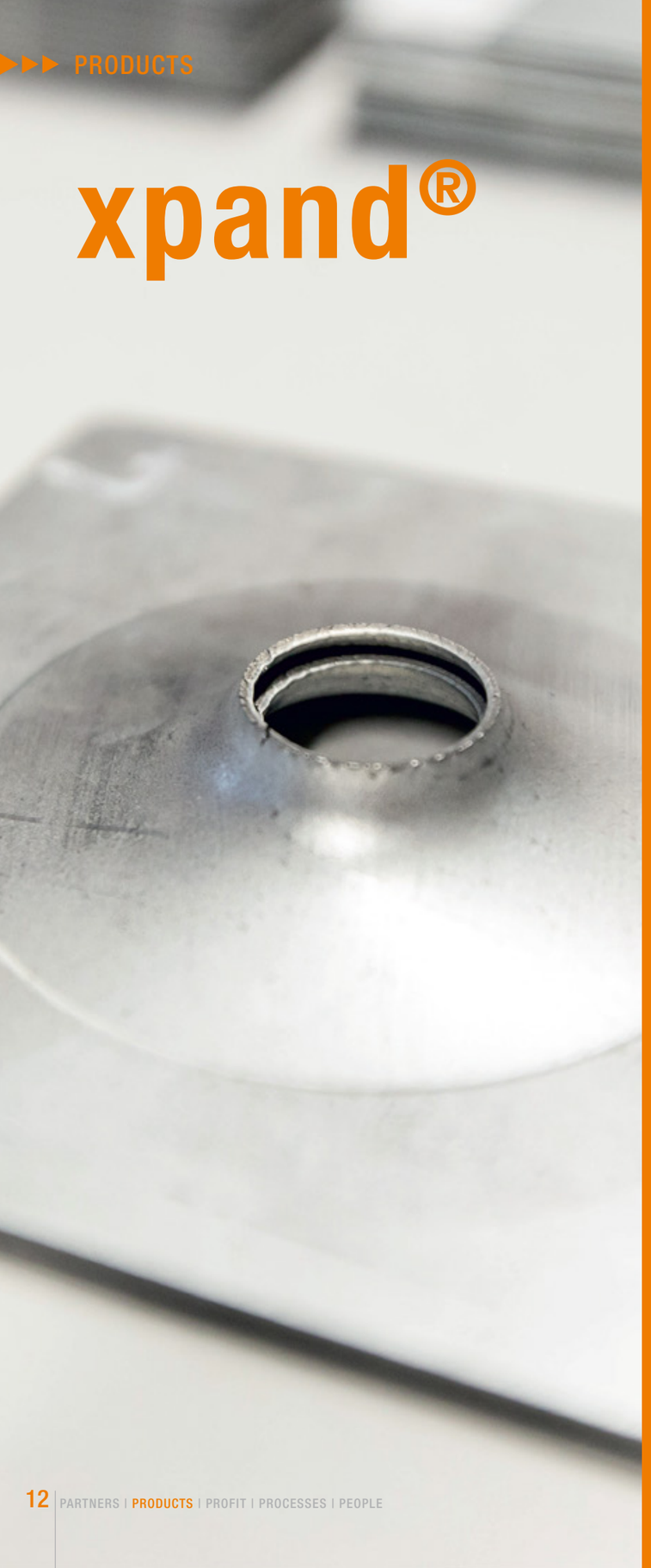
In a subsequent discussion in the administrative building, Bernd Decker makes it clear that, without high-quality steel, the company could not achieve its own performance. The close cooperation with Salzgitter Flachstahl, from the joint development to series production of crash-relevant car body structures, ultimately led to the conclusion that also ended up convincing car manufacturers: “Our contacts in Salzgitter were able to make it clear very early on that only they have the required qualities and dimensions on the market.” His colleague Ralf Krähe adds: “The technical know-how flowed in both directions, both Salzgitter Flachstahl and Tower International profited from it. At the basis of the success were the simulations which were jointly analyzed at an early stage. Other important factors were the aspect of manufacturability as well as the development of material and design changes”. If the material delivered has a uniform quality, the goal is reached quicker. In addition, the integrated cooperation with Salzgitter Flachstahl and Salzgitter Europlatine meant that a considerably more stable process could be developed, which also paid off in concrete terms in the price and the production result.

“We decided to use the HCT980XD from Salzgitter Flachstahl, because the competition couldn’t provide us with cold-rolled steel in the required format that enables us achieve the intended results,” explains Bernd Decker regarding Tower Automotive's decision. “By contrast, in Salzgitter we find the strongest cold-rolling mill in the world, above all when it comes to production of the coil width, which is relevant for our products.” These advantages are the reason for the continuous intensive cooperation in the area of high-strength, cold-formed chassis structures.

Between 8,000 and 9,000 tons of steel are delivered each year from Salzgitter and processed in Zwickau in the presses, primarily for Porsche and Volkswagen. “The investment in our high-performance transfer presses has paid off. It permitted us to implement the intended lean production process in excellent manner. And the quality of the material provided by Salzgitter Flachstahl ensures that this can de facto be achieved in day-to-day production,” says Krähe in reference to the relevance of the steel quality. “Even in the early stages of a new product, we work together with our colleagues from Salzgitter, and are able to submit reliable proposals at an early stage - also simply because we’ve gotten to know each other well,” adds Decker. Ralf Krähe formulates things technically at the end of the interview: “Over time, the good cooperation has welded us together to an extent”. ◀

▲ **Know-how right from the start:** Trainees check a side member for the BMW X1 in the measuring room

▲ **Good simulation equals good production:** Forming simulation in the run-up to production



xpand®

WHAT IS **xpand®**?

The development of new light-weight construction solutions in automobile manufacturing calls for the manufacture of increasingly complex component geometries. In order to also guarantee a high level of process reliability during critical forming steps, Salzgitter Flachstahl has enhanced many of its higher-strength steels. This new generation of steels has the term xpand® added to its name.

The term xpand® is based on the Latin word “expandere” (= extend, expand) and stands for guaranteed increased capacity for hole expansion in the steels. The hole expansion value λ of a material characterizes the resistance of the material to crack propagation and is a measure of its edge crack sensitivity and deformability of the edge. The value is determined in the hole expansion test per ISO 16630. The xpand® steels' forming characteristics are optimized by the higher hole expansion ratio and enable the manufacture of more complex component geometries. This permits new light-weight construction solutions to be created thanks to component-centered design, reduced sheet thickness and component integration. Additionally, this increases the customer’s process stability. Because of the reduced susceptibility to edge cracks exhibited by xpand® steels, the risk of failure can be reduced, even in the case of e.g. reduced sheet thickness for a component. This guarantees the customer a secure setting for its production processes – even for critical forming.

This new material generation of xpand® steels enables Salzgitter Flachstahl to provide unique solutions for lightweight automotive construction. Thanks to its xpand® steels, Salzgitter Flachstahl is the only steel producer in the world to guarantee the following hole expansion values for the grades below:

Grade		Guaranteed hole expansion
HCT600XDxpand®	Cold strip	50 %
HCT980XDxpand®	Cold strip	20 %
HCT780XDxpand®	Cold strip	40 %
SZBS600xpand®	Hot strip	75 %

HOW IS **xpand®** MADE?

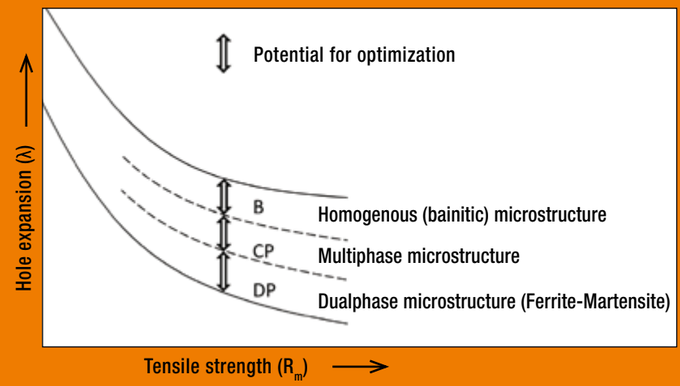
Thanks to the long-term development of the xpand® grades, Salzgitter Flachstahl ranks as a pioneer in the development of steel grades with low susceptibility to edge cracking. This expertise enables Salzgitter Flachstahl to use its complex process control and detailed material knowledge to adjust the high hole expansion values of its multi-phase steels.

Various influencing factors have to be taken into account in order to achieve the outstanding properties of the xpand® steels, in particular the low susceptibility to edge cracking. Besides analysis, important measures for increasing the hole expansion include the targeted adjustment of the material structure. Of decisive importance are the proportions, the size, the distribution as well as the properties of the phases in the material structure. A material’s resistance to crack initiation and propagation is improved, in particular, by extremely homogeneous microstructures and/or slight differences in the hardness of their structural components.

Bainitic steels, such as the SZBS600xpand®, are characterized by a basic structure of ferrite and bainite with comparatively low differences in hardness. Dualphase steels such as the HCT600XDxpand®, on the other hand, have a two-phase structure consisting of ferrite and comparatively hard martensite. This is one of the reasons why bainitic steels have a lower susceptibility to edge cracking than dualphase steels.

A further important influencing factor for hole expansion is the form of the respective material structure. It is also important to note that as the tensile strength increases, hole expansion decreases across all strength classes.

This complex interplay between chemical analysis, process management and material science comprises the “cooking recipe” for the extraordinary properties of the xpand® grades from Salzgitter. ▶

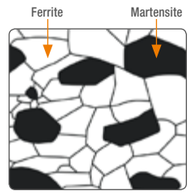


Simplified schematic presentation according to SZMF ▲

Dualphase steel

- Basic ferrite matrix
- Martensitic second-phase (insularly embedded)

> jumps in hardness between phases

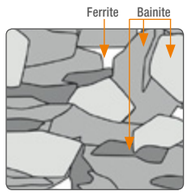


▲ Dualphase steel

Complex-phase steel

- Basic ferrite-bainite matrix

> Homogenous hardness distribution

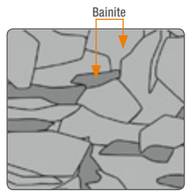


▲ Complex-phase steel

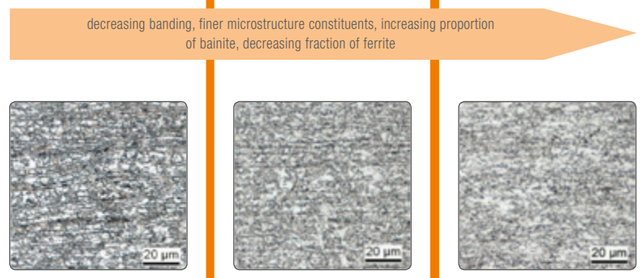
Bainitic steel

- Homogenous bainitic matrix

> Homogenous hardness distribution
> Strong congruencies



▲ Bainitic steel



NEW GENERATION OF DUALPHASE STEELS – HCT600XD**xpand®** AND HCT980XD**xpand®**

The main challenge in vehicle construction is to reduce the chassis weight while concurrently meeting the high demands placed on the vehicle's passive safety. In order to achieve these objectives, steels are increasingly being used in new vehicle generations, steels which have high strength while also offering good formability. Dualphase steels fulfill this objective particularly well. Further development of Salzgitter Flachstahl's grades HCT600XDxpand® and HCT980XDxpand® has enhanced the proven basic characteristics of the dualphase steels by the addition of outstanding suitability for edge forming. This modern material from the latest generation permits very complex component geometries to be achieved. This is especially true because the material - including the edge - offers high forming capability. This is due to the markedly increased hole expansiveness compared to conventional dualphase steels. Due to the component-appropriate design and the reduction of the material thickness, this new material generation makes a considerable contribution to lightweight automotive construction. A lightweight construction advantage of up to 20 % can be achieved compared to conventional micro-alloyed steels.

NEW GENERATION OF COMPLEX-PHASE STEELS – HCT780CD**xpand®**

The complex-phase steels differ from the dualphase steels in that they have a higher yield strength, but also a somewhat lower total elongation. They also have very good fatigue strength. This makes them ideal for use in components which are subject to dynamic loads, e.g. as is the case for chassis components. In addition, the new material generation of the xpand® steels offers a low edge cracking sensitivity and resulting increased hole expansion. The xpand® steel HCT780CDxpand® is therefore a problem solver for difficult forming processes with high strength. Consequently, this guarantees high process reliability in the production process. ◀

Replacing the standard series material for this D-column reinforcement with a hot-dip galvanized dualphase steel from the new generation enabled the component weight to be reduced by some 17 % thanks to a reduction in sheet thickness. ▶

◀ Bainitic steels are distinguished by their excellent formability and high strength. Their excellent properties under dynamic load conditions make them ideal for applications in the chassis area.

The mechanical properties of the dualphase and complex-phase steels also meet the requirements of the automotive industry (e.g. VDA 239-100) with the test direction along the rolling direction and DIN EN 10346 with the test direction at right angles to the rolling direction.

The bainitic steels are delivered according to Salzgitter's material data sheet.

xpand®

A feasibility test on the use of the new-generation xpand® dualphase steels was carried out for a seat cross member in cooperation with an automotive manufacturer.

Replacing the standard material HX340LAD with a dualphase steel enabled a reduction in sheet thickness of

0,009 in.

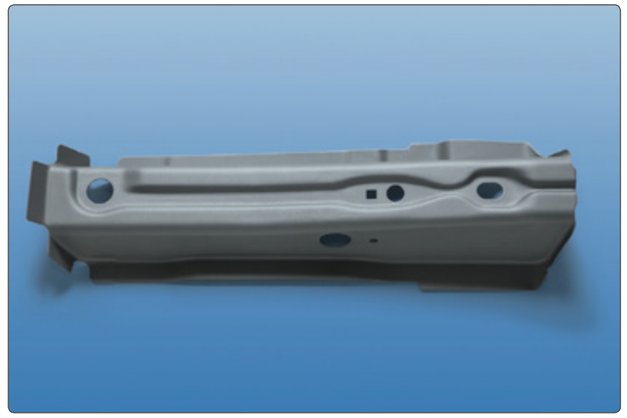
This results in a weight reduction of

19 percent, i.e. some

280 grams per part.

This allows the overall weight of the vehicle to be reduced by

0,560 kilograms.



Forming out to the edge

DETERMINING EDGE CRACK SENSITIVITY

Figure 1 shows typical critical areas on a chassis component.
In addition to stamped and subsequently raised component edges, this also includes edge areas with a high degree of forming and sleeving of stamped holes. ▼

Reducing the weight of automotive components with the goal of minimizing CO_2 emissions is currently one of the key challenges facing the automotive industry. The result: the steel grades used are becoming ever stronger, the sheets used are becoming ever thinner, and component geometries are becoming more and more complex. Consequently, with each new component generation the demands on the mechanical properties of the prematerial are increasing.

It is becoming increasingly necessary to precisely analyze and describe material properties and processing limits. Upstream processing steps must be factored in at an early stage. The so-called Forming Limit Curve (FLC), which is determined according to standard ISO 12004-2, is a common means of determining the deformation limits of a material. This characterization is strictly limited to the basic material. The deformability of a sheet edge produced by shear cutting cannot be satisfactorily reproduced by means of an FLC or a tensile test. The reason for this is the damage introduced during shearing, which significantly reduces the formability of the sheet edges, especially in the case of high-strength/stronger strength steels. In this context, steels which are sensitive to pre-damage at the edge are referred to as being sensitive to edge cracks. Consequently, an additional test is required when forming an edge which is generated by shear cutting and thus exhibits pre-damage.

There are a number of test methods to quantify the edge crack sensitivity of a material. Currently, the standardized and most widely used test method is the so-called hole expansion test according to ISO 16630. In this test, a hole with a diameter of d_p = 10 mm is punched into the sheet metal sample by shearing and then expanded with a conical punch. The expansion is halted by the operator as soon as he or she detects a crack which extends through the entire sheet thickness.

The test result is given by the so-called hole expansion ratio, which is defined as the ratio of the increase in the hole diameter (D_H to D_0) to the original hole diameter D_0 (Figure 2)

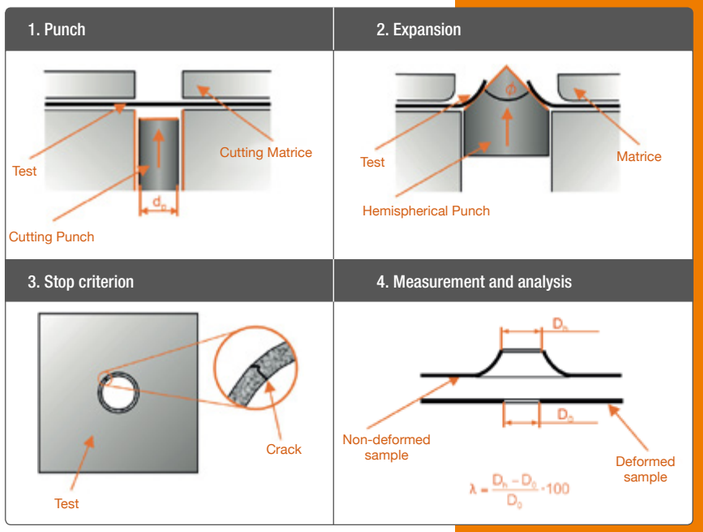


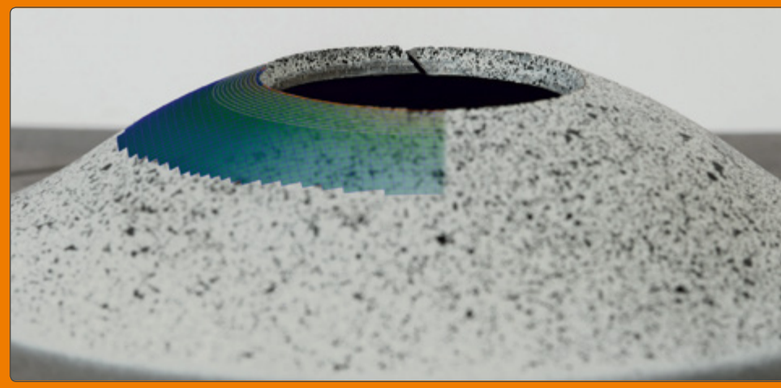
Figure 2: Schematic sequence of the hole expansion test per ISO 16630 ▼

The standardized hole expansion test is used not least because of its comparatively simple execution as a rapid test as well as a material approval test for Salzgitter Flachstahl. Nevertheless, to achieve a targeted component design and to provide parameter values for the numerical transformation simulation, information is required which goes beyond that which is determined by means of hole expansion tests according to ISO 16630. Consequently, further edge-crack tests are developed in cooperation with Salzgitter Mannesmann Forschung, e.g. the so-called hole expansion test with Nakajima punch, and are used to determine parameter values. For this hole expansion test, the test setup is used to determine a forming limit curve. As in the case of the ISO 16630 hole expansion test, the experiment consists of four process steps. First, a hole with a diameter of 20 mm is pierced into a square sample (edge length 200 mm) by punching. In the second step, the prepared sample is expanded with a hemispherical punch (diameter 100 mm). The test is immediately stopped as soon as a crack forms which extends through the entire sheet thickness. As is the case with the ISO 16630 hole expansion test, at least three samples are tested per setting. In contrast to the hole expansion test according to ISO 16630, the test arrangement permits the use of optical measuring systems, whereby characteristic values can be determined independent of the user and test result scattering can be significantly reduced.

For this purpose, a stochastic pattern is applied to the sheet metal surface prior to forming, and a detailed strain analysis for the region close to the edge of the sample is carried out using an optical measuring system (see Figure 3).

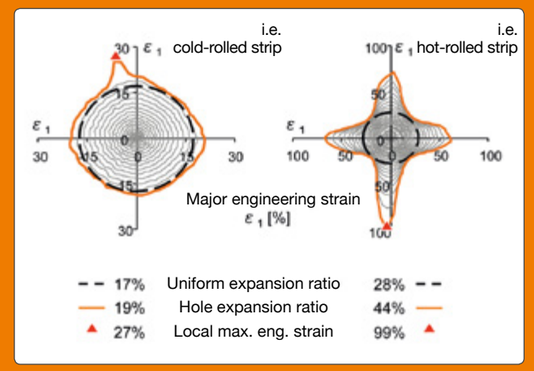
The point in time at which cracking occurs, as well as the hole expansion ratio, can be determined automatically with the help of an evaluation macro which has been developed by Salzgitter Mannesmann Forschung and which contains defined cracking criteria. As a result of this edge crack test, in addition to the hole expansion ratio already described above, information can be gleaned regarding the timeline as well as the regional allocation of the locally occurring strains. Figure 4 shows typical examples of this strain distribution for both a cold strip and a hot-rolled strip in the form of a polar diagram. It is possible to see the temporal development of the main strain of a single circular section with a defined distance from the sheet edge. In the case of the cold strip, the expansion around the circumference of the hole up to the crack is homogeneous. By contrast, in the case of the hot-rolled strip, whose elongations are at a significantly higher level, localized elongations occur laterally and transversely with respect to the rolling direction at a certain point in the deformation.

The characteristic values determined in this way for the deformation behavior of the materials in the region close to the edge can be used specifically for the component as well as for the process design. In the component design phase, the characteristic values serve, for example, as a feasibility criterion and, in the process design, to position and nest components optimally on the strip with regard to the material stress.



▲ Figure 3:
Widened sample of the hole expansion test with Nakajima punch with stochastic pattern and performed strain analysis.

Consequently, the test methods used by Salzgitter Flachstahl to measure the edge cracking sensitivity provide customers with reliable insights that ultimately serve to optimize the efficiency of processes. ◀



◀ Figure 4:
Polarization of the main extension for a typical cold-rolled and hot-rolled strip as a result of the strain analysis for the hole expansion test with Nakajima punch

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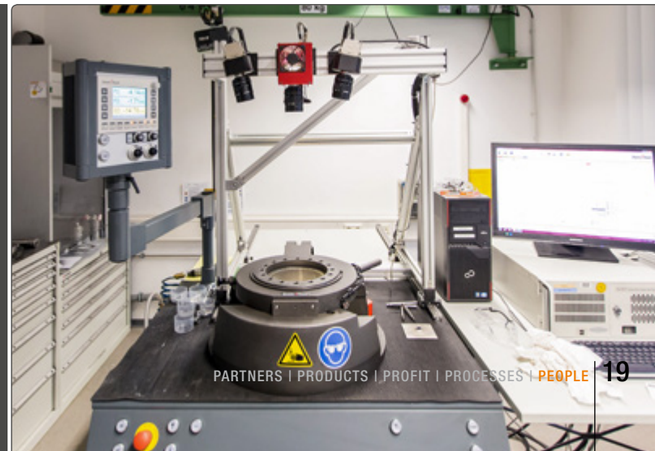
Publisher: Salzgitter Flachstahl GmbH

Responsible for content: Frank Heidelberger

Concept and design: AL°L 2.0 GmbH, Münster, www.all-zweipunktnull.net

Printed by: Salzgitter Flachstahl GmbH

Print run: 800



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