Hot sheet metal forming: the formulation of graded component characteristics based on strategic temperature management for tool-based and incremental forming operations.

Neugebauer, R.; Schieck, F.; Rautenstrauch, A.; Bach, M.

Abstract

For some years press-hardening has been a fixed variable in the manufacture of high-strength structural components. Advantages to be derived from the press-hardening of components advantages include, for example, high strength with low sheet thicknesses; this offers the potential for weight saving and has finally been successful in convincing automotive manufacturers.

Bodywork concepts designed to take into account crash requirements, in addition to a general increase in strength characteristics, are also increasingly calling for zones of various characteristics to be embodied within the relevant structural components. These requirements are fulfilled by means of so-called "Tailor Products" which can be manufactured, for example, by using a laser weld to combine different materials or by rolling different sheet thicknesses of the input material.

An alternative approach is to introduce material characteristics at a local level without changing the sheet thickness / structure of the material. By adopting a specific temperature regime in the tool, characteristics zones can be set that demonstrate different tensile strengths and degrees of permanent elongation. This means that complicated input material configurations become a thing of the past, at the same time promising not only a shortening of the process chain but also a reduction in costs.

1 Introduction

The discussion centering on the reduction of CO_2 emissions in motor vehicles and the political guidelines associated with this topic are bringing about a clear change in the direction of thinking within the automotive industry. The increase in vehicle weight is directly related to requirements in terms of comfort and safety. The electrical equipment (drive assistance system) is intended to take more and more pressure off the driver in traffic, but none the less brings with it an increase in the weight of the vehicle. This increase in weight needs to be counteracted in other areas, for example, by devising lightweight construction concepts for the bodywork.

For some time now there has been evidence that the press hardening process offers major potential when it comes to coping with the increasing demands on the structural components presented by lightweight construction and crash safety. By using hot sheet metal forming it is possible to achieve a greater deformation capability and, at the same time, to reduce the force required for the forming operation. During forming, high rates of cooling are achieved and it is these that ultimately bring about a transformation into martensite. This material formulation results in a high level of tensile strength which is, however, prejudicial as far as the subsequent machining stages such as trimming are concerned. This is evident from the high level of wear on the cutting tools, something which can only be countered by resorting to cost-intensive laser beam cutting *[1]*.

Up to now hot forming of the sheet, in particular press hardening, has taken place homogeneously across the component, which means that the component does not exhibit any defined characteristics zones. However, when it comes to load-bearing bodywork parts that are also of relevance for safety, it is precisely these different component characteristics that are in demand. This is why the component elements have hitherto been manufactured individually and joined together afterwards to form a component. Using hot sheet metal forming makes it possible, with the help of specific process formulation and tool adaptation, to make a start here. At the same time, existing structural assemblies can be combined to form a single individual part, which distinctly reduces the number of components and the associated joining operations *[2]*.

2 State-of-the-art Technology

2.1 Requirements applicable to Structural Components

The safety concept layout for the side of the motor vehicle is shown by way of an example in Fig. 1. It is evident from the IHS side crash test that the highest stress is not on the sills but on the B-pillar which needs to be of correspondingly massive design and duly reinforced. The B-pillar is supported in the upper area by the roof crossmember and the A-pillar/roof frame and in the lower area by the side sill as well as the seat crossmember. Based on the load path shown the central importance of the B-pillar in turn becomes clear *[3].*

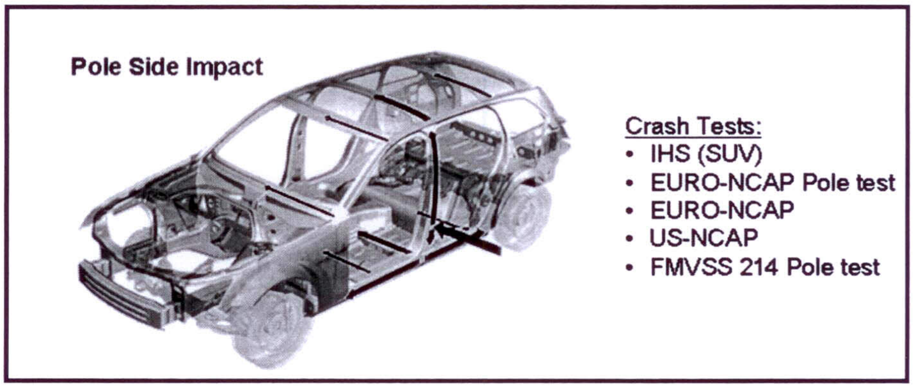


Fig. 1: Pole Side Impact [3]

The enhanced crash requirements and, linked with these, the use of high strength steel materials have resulted in the development of a material mix which aims to take into account the different component characteristics and fulfil their corresponding requirements in relation to bodywork. From this various approaches emerge, both technology- and materials technology-related.

Fig.2 illustrates, taking the B-pillar as an example, how the individual characteristics zones can be divided up to correspond with the safety requirements of the EURO-NCAP test. The layout of the components in accordance with the requirements may be implemented by means of a specific thermo-mechanical process management operation. By controlled formulation of component characteristics it is possible to achieve improved crash performance in addition to increased levels of rigidity. The result is not only an increase in strength but also specific localized loss of cohesion in the material.

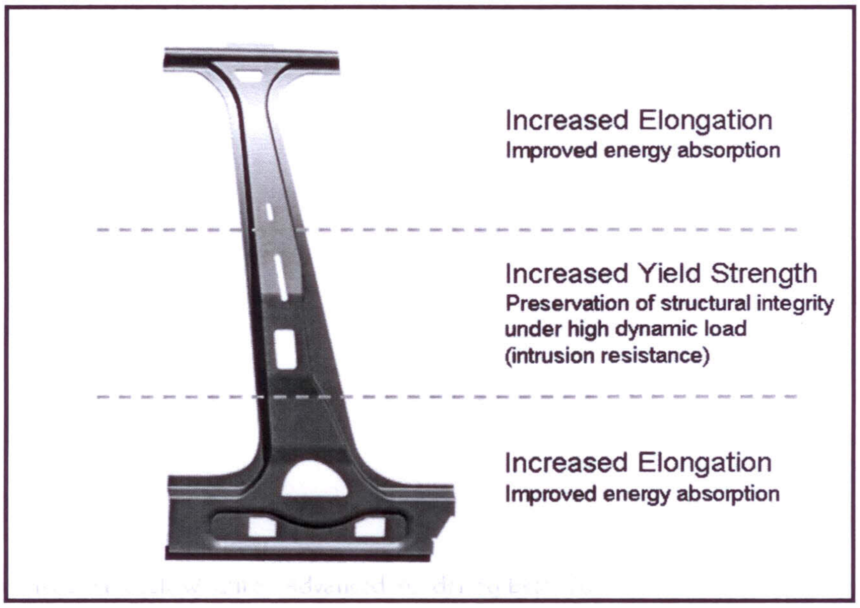


Fig. 2: B-pillar - optimized component properties for improved crash performance

In the top section of the B-pillar there are higher strengths to be formulated that, in the event of a side impact crash, will protect the driver from direct impact. To compensate for the kinetic energy that develops in a collision, the bottom section of the B-pillar – the B-pillar foot - is smoother in terms of its design; the point of this is to break down the crash energy by means of specific deformation.

The requirements can be met using various different technologies. In the following we shall set out to examine the approach involving hot sheet metal forming in press hardening and in roll forming.

2.2 Sheet Metal Hot Forming – Press Hardening

Press hardening may be subdivided into two process variants, direct and indirect press hardening. In a direct operation process chain the metal blank for austenitization is cut to size and heated in the furnace at approx. 950 °C. The heating process is followed by the hot forming of the sheet metal in a cooled tool. The high cooling rate of at least 27 K/s required here results in hardening due to the transformation into martensitic structure. Depending on the material used, this gives the components a tensile strength of 1000 to 1900 N/mm².

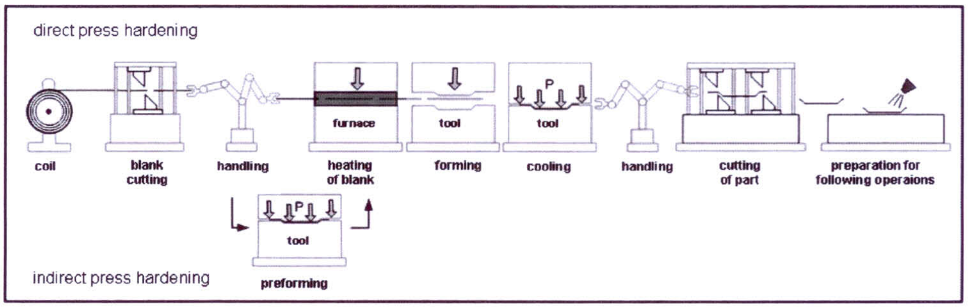


Fig. 3: Schematic presentation of direct and indirect press hardening

In the indirect process variant, a single- or multi-stage cold forming operation takes place prior to heating which, as a general rule, leads to a preforming of up to 95 % of the final geometry. It is only after preforming that the components are austenitized in the furnace and, as with the direct process, delivered to the cooled tool for end forming and press hardening, in essence involving only one calibration process *[4,[5].*

2.3 Optimization Approaches in Press Hardening

It is well known that press-hardened components can be distinguished by their high levels of strength and rigidity, although these factors may also incorporate disadvantages. They are associated with low levels of percent elongation at failure and ductility which have a negative effect on crash suitability. Currently there are numerous factors under consideration which deal with the subject of how to make specific improvements to these characteristics of structural components.

Basically, it is possible to influence the material characteristics by changing the alloy composition. These material characteristics may be assumed to have their origins in the way the boron / manganese components (which, in addition to carbon, exert the greatest influence on hardenability in steel) are assimilated.

Another possibility when it comes to hot sheet metal forming is the use of 'tailor' products'. The idea of customized blanks for 'tailor' products is derived from the requirement to manufacture components demonstrating different characteristics zones within themselves *[6]*.

First of all, for plant-engineering reasons, blanks with the appropriate characteristics features are joined with one another by means of laser welding – these are the so-called 'Tailor Welded Blanks'. Initially only simple joints existed between two sheets of the same type with different wall thicknesses; nowadays complex steel sheets with different thicknesses and/or strengths can be joined with one another *[7]*.

The 'Tailor Rolled Blanks' are sheets with defined thickness profiles in the longitudinal rolling direction. Due to the continuous changes in thickness, special features emerge which need to be taken into account in any subsequent deep drawing process and, above all, as far as the tool is concerned. In addition to adapting the tool geometry to the thickness curve, the length, position and the orientation of the transition are also important *[8]*.

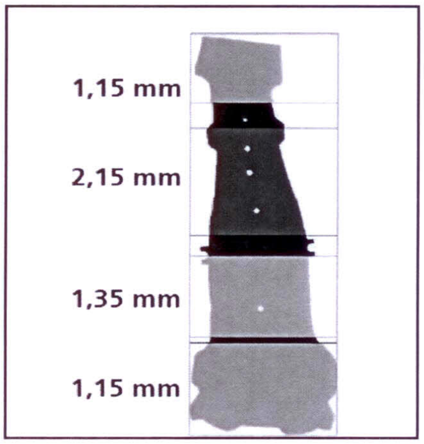


Fig. 4: left - Tailor rolled blank [VW] ***right - Tailor welded blank [ThyssenKrupp]***

A further approach is to use blanks that have been subjected to localized variations as regards tempering prior to forming. This variable tempering can be halted following heat treatment by means of specific cooling or heating of the blank before it is sent for form hardening. Cooling can, for example, be carried out by blowing air onto the blank, below austenitization temperature. A martensitic structural transformation would not take place during press hardening in this component zone and instead a lower level of strength coupled with higher ductility would come about *[9]*.

In conjunction with this, Volkswagen AG has put forward some initial thoughts on optimizing the process segment and influencing component rigidity by means of specific thermo-mechanical process management. Fig. 5 shows how, in practical implementation, the austenitized sheets are subjected locally to air cooling prior to forming. The air-cooled area has a lower forming temperature in the forming tool and as a result experiences a lower rate of cooling, something which results in reduced component rigidity.

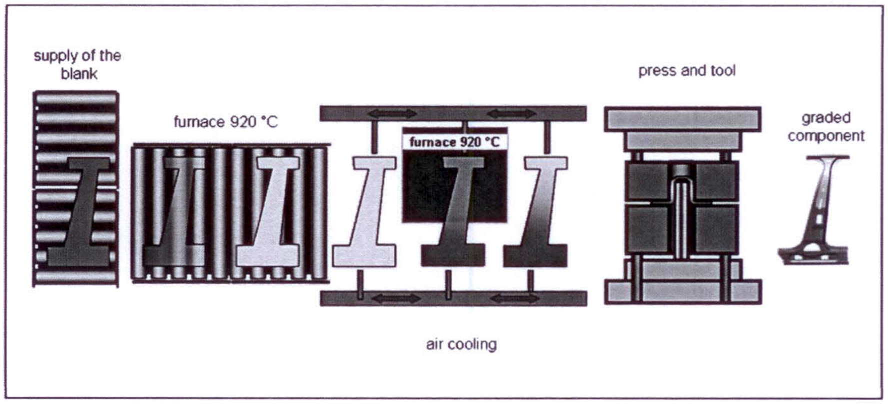


Fig. 5: Production concept B-pillar - graded properties through heating route

For configuring different component characteristics zones, the forming process may also be followed by a specific heat treatment. In Patent Specification DE 197 43 802 C2 a process is described whereby, with the help of an inductor, a temperature of 600° - 900°C is set (partially within 20 - 25s) and where the component subsequently undergoes repeat tempering in the press tool. In the austenitized areas the transition to martensite takes place as a result of the tempering which brings about a corresponding increase in strength *[10]*.

2.4 Roll Forming with Integrated Heat Treatment

Roll forming is a continuous process for generating open or closed hollow profiles from strip material in a very wide range of cross-sections. For this the semi-finished item – either endless or as a blank – is formed incrementally stepwise using a number of rolling stands. At the same time forming takes place in the profile gaps created in the upper and lower rollers. Fig. 6 visualizes the process in a schematic.

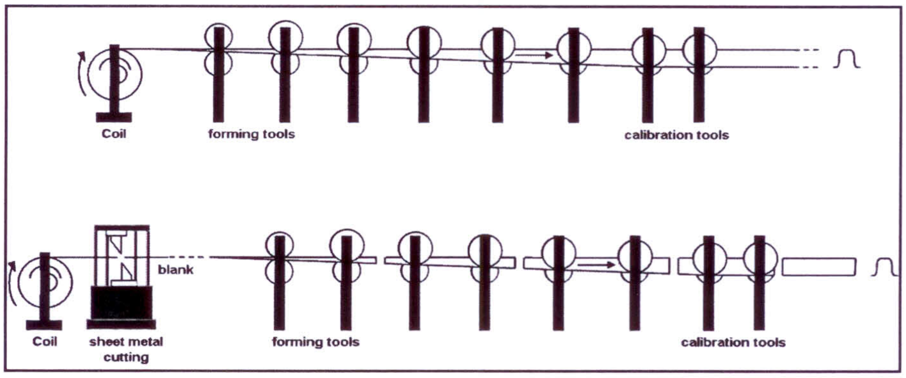


Fig. 6: Schematic showing roll forming; top: endless, bottom: blank

In *[11]* a process is introduced which makes it possible to create variable strengths at different, previously defined points on a linear semi-finished item without changing the thickness of the metal. For this the workpiece is heated at the corresponding points inductively to austenitization temperature because this method makes marked-off zones definable and ensures a short period of heating. Quenching takes place on infeed to a cooled pair of rollers. A cooling medium can also be used to increase the temperature gradient. Following specific hardening, the processes of deep drawing and die bending can be deployed in addition to roll forming. In order to avoid any crack formation or an increase in process forces it will be necessary to cut out the areas of increased strength in subsequent forming processes.

Linde & Wiemann GmbH KG carry out hot rolling of hardenable boron steels using ACCRA technology. This enables precisely defined, partially hardened or ductile areas to be formed on 3-dimensional components, including those with variable cross-sections, without any flaws in material or thickness. In this way it is possible to formulate pre-defined characteristics and crash behaviour. At the same time the strength of the profile is, in essence, dependent on the position and number of hardened areas *[12]*.

A further heating strategy is set out in *[13]*. Basically used for expanding the boundaries of forming and the associated potential minimization of the bending radii, as well as reducing any deviations in form *[14]* in profiling operations, this involves local heating in the bending radii of super-high strength steels using diode lasers (see Fig. 7). It is therefore feasible to link this technology with defined cooling and to use it for tempering the material. However, with the laser, there is a risk that, if the temperatures are too high, the surface will melt and therefore it will no longer be possible to use the component.

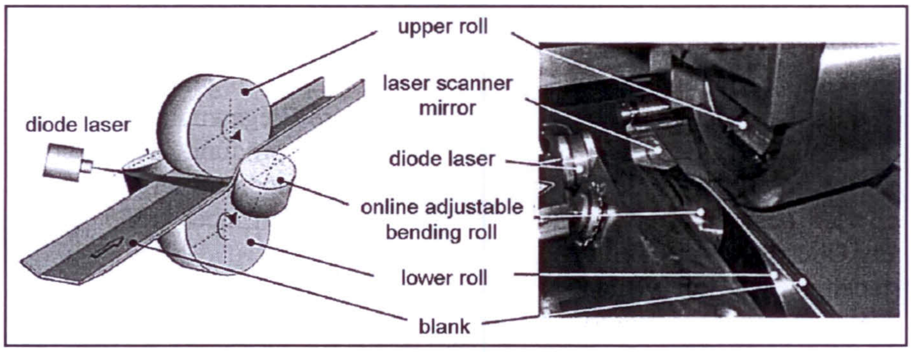


Fig. 7: Schematic showing one-level roll forming system with integrated laser [10]

The blanks, which are to an extent also preformed, are austenitized in a continuous furnace. Heating formed components is more difficult in a continuous furnace and for this reason heating concepts such as conduction or induction become more attractive. The use of conductive and inductive heating principles enables increased heating up speeds to be achieved. Nevertheless, very high temperature gradients, as well as the low level of effectiveness and the associated high power consumption, constitute arguments against conduction *[15]*.

The induction procedure has already been successfully introduced in *[16]* and can therefore also be used for roll profiling. Here profiles are heated inductively "in-line" and quenched using cooled rollers more quickly than the respective critical cooling speed for the corresponding material. At the same time coils around the profile are so arranged as to enable localized heating. Using inductive heating, defined degrees of hardness and gradients can be achieved with smooth and effective transition zones.

In the Aachener Kolloquium für Fahrzeug- und Motorentechnik 2005 mention is made of the fact that load-adjusted material behaviour is possible only with partial tempering (see Fig.8). The transition zones between tempered and untempered steel are between 40 and 50mm in width *[17]*.

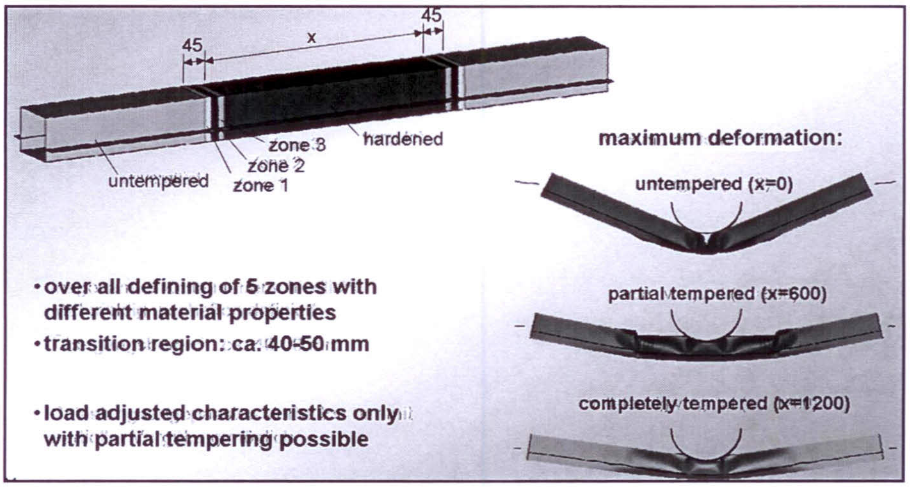


Fig. 8: Structural improvement for side crash [17]

The extent to which the choice of heating and cooling device can be influenced should be determined on the basis of a technical inspection of the materials.

3 Research Requirement and Procedure

3.1 Introduction

The 'Tailor Products' described above represent a high level of production expenditure. Although components with different characteristics zones are produced, these nevertheless consist of a number of different individual parts and have to be joined using joining operations such as welding to tailor-welded blanks. One disadvantage of tailor-welded blanks is the fact that, following press hardening, the coatings (which mostly consists of AlSi), has to be removed by recourse to a cleaning stage (e.g. abrasive blasting of the surface). The two chemical elements, aluminium and silicium, do not volatilize when the individual blanks are welded; instead they become rigid, forming a primary proeutectic in the weld and thus creating weak points there *[8]*.

The approach involving the specific formulation of characteristics via the temperature regime does not call for any complicated semi-finished item preparations such as rolling a blank with a variable sheet thickness gradient or follow-up operations like welding. The intention is to implement soft intersection and crash zones coupled with hardened component zones through specific temperature management by recourse to differentiated heat discharge in the forming tool.

There is potential here for a reduction of the need to invest in laser trimming as this can be replaced by more cost-effective technologies. As regards the implementation of this concept, it is possible to fall back on existing installations and there is no need for any expensive reconstruction or purchases. Furthermore, as a result of combining a number of process stages into one forming stage with controlled temperature distribution, production time will be saved.

3.2 Thermo-mechanical Studies

This approach relates to the formulation of different characteristics zones with the help of specific temperature management from heat treatment right through to forming. By means of specific heat utilisation not only can energy efficiency be increased but cost savings can also be made. With corresponding structuring of the process chain even entire process stages can be combined, something which will generate savings in relation to time, cost and space availability.

The process chain is first of all laid out based on a fundamental thermo-mechanical study and varying different parameters such as forming temperature, degree of forming, heating and cooling rate and austenitization temperature, process times etc. This approach is shown In Fig. 9 in the form of a sketch. An important factor in the studies is the characterisation of the materials as regards their mechanical characteristics and temperature behaviour.

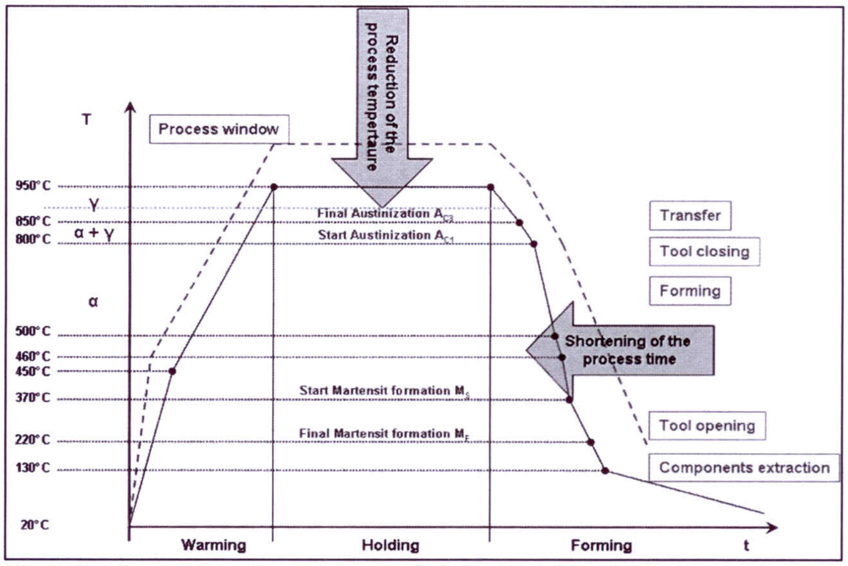


Fig. 9: Time/temperature diagram showing hot sheet metal forming

Initial studies aimed at identifying the thermal and mechanical characteristics have already been carried out by various research institutions in relation to hot sheet metal forming and these make a good starting point *[13], [15], [18]*. However, up to now only one material and a single technology have been included in the considerations, so that there is no opportunity for comparison.

The thermo-mechanical studies into how hot sheet metal forming is structured were conducted on two different materials - manganese boron steel 22MnB5 - MBW1500 produced by Messrs. ThyssenKrupp Steel Europe and the air-hardening heat-treated steel 10MnCrMo8-3-2 - LH800 supplied by Messrs Salzgitter Flat Steel. Both steels were initially developed for completely different areas of technological application, they nevertheless stand out due to their very good hardening capability that makes it possible for strengths in excess of 1000 N/mm² to be achieved. Whereas hot sheet metal forming has for many years represented the state-of-the-art technology as far as manganese boron steels are concerned, LH 800 was originally developed for cold sheet metal forming with subsequent heat treatment and hardening in air.

In collaboration with Salzgitter Flat Steel, discussions were also held on formulating a process route comparable to that of manganese boron steel and implementing it within the framework of initial studies. In a combination of heat treatment with forming, using the process sequence familiar to us from press hardening, these demonstrate positive results which form the basis for further analyses. A long holding time in the tool is not required for hardening the formed components. The components can be removed from the tool while they are still in the hot state and allowed to harden in exposure to air.

The aim of studies carried out on the LH800 is, as is also the case for the classic boron manganese alloyed steel, to produce graded components incorporating different characteristics zones, something which presents current technology with new challenges. Within the framework of sächsisches Spitzentechnologiecluster eniPROD, studies are being carried out first of all to devise the necessary principles for process management and then to transfer these to real part geometries.

Within the framework of the basic investigations, special Continuous Cooling Transformation diagrams (CCT diagrams) were initially drawn up for the two materials. Included in the considerations were some extremely variable cooling rates of 0.2 K/s to 60 K/s (see Fig.10), the aim being to obtain a statement on the special temperature regimes of the materials for subsequent transfer to the variable characteristics zones in the component within the context of further investigations.

The initial austenitization temperature Ac1 and the end austenitization temperature Ac3 were calculated in accordance with Spur and Stöferle.

Ac1 Temperature

$$Ac_1 = 739 - 22 \times \%C + 2 \times \%Si - 7 \times \%Mn + 14 \times \%Cr + 13 \times \%Mo - 13 \times \%Ni + 20 \times \%V \quad (1)$$

Ac3 Temperature

$$Ac_3 = 902 - 255 \times \%C + 19 \times \%Si - 11 \times \%Mn + 5 \times \%Cr + 13 \times \%Mo - 20 \times \%Ni + 55 \times \%V \quad (2)$$

The basis of the regression formula is the chemical composition of the material *[8]*. A heating temperature of 900 °C for austenitization was applied correspondingly for both materials with a view to being able to compare the results with one another in the evaluation; the other test parameters for both materials were chosen so as to be identical for both materials.

The evaluation of the CCT diagrams comprised, within the framework of work previously carried out, only the hardness measurement and the study of the microstructure. However, as far as the continuance of the project is concerned, the mechanical end characteristics are also of significance. These ultimately provide information on the crash behaviour of structural components. For this reason further studies were conducted with the aid of micro-bending tests because the dilatometer samples which are required for compiling the CCT diagrams are restricted in terms of their geometric dimensions (10 x 5 mm).

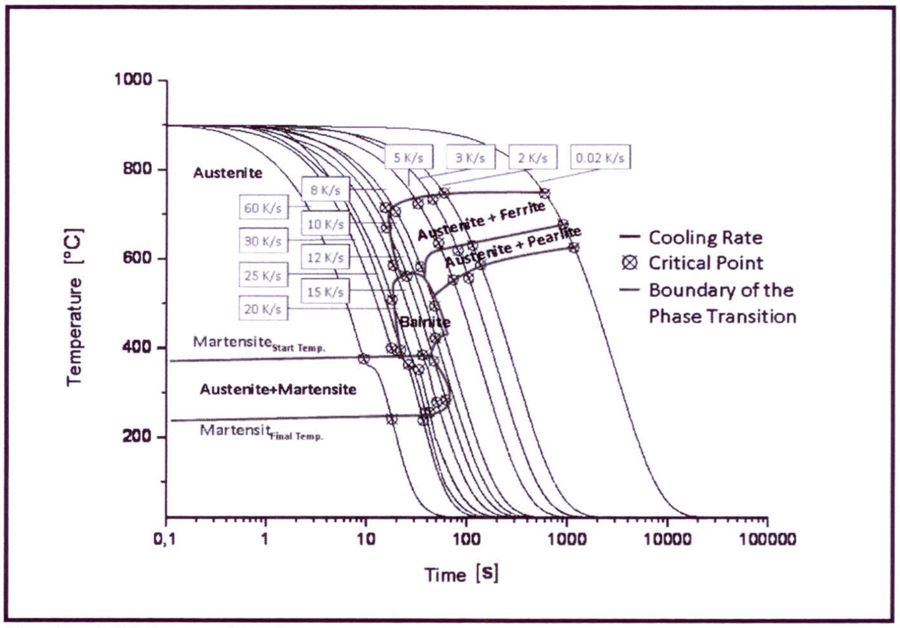


Fig. 10: CCT-diagram 22MnB5

Moreover, the uniaxial stress state, as represented by the tensile test, was carried out both at ambient temperature as well as at higher temperatures in order to determine the mechanical characteristics under thermal loading. The tempered tensile test was designed in such a way that the tensile test samples were first of all austenitized and, in the next stage, stress was applied at a defined forming temperature. The test modification served as a rudimentary replica of the actual process, the aim being to thus portray the mechanical characteristics of the materials during hot sheet metal forming.

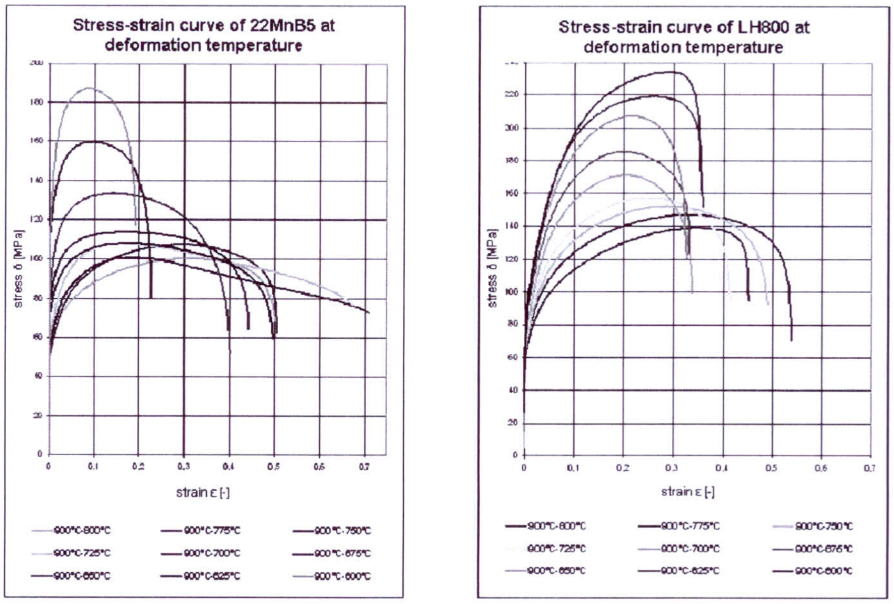


Fig. 11: Stress/strain curve (right: 22MnB5, left: LH 800)

The results of the materials analyses serve as the basis for further technological studies. Specific temperature management is to be trialled and implemented for two different technologies. Further analyses relating to hot sheet metal forming using deep drawing and roll forming techniques are planned within the scope of the works.

3.3 Experimental Studies

3.3.1 Tool-specific Forming (Press Hardening)

When it comes to the design of the tools for carrying out hot sheet metal forming by means of deep drawing, the basic forming technology studies are important in addition to the materials analyses. The aim of the research is to increase process reliability by a more precise formulation of the characteristics fields in the component.

The materials diagrams determined represent the basis for a specific process layout. Basic tests in conjunction with bending, stretch forming and deep drawing operations are to be carried out with a range of different parameter combinations (see Fig. 12). Test series with various blank temperatures and a range of different tool temperatures are planned. For statistical validation purposes, a minimum of three tests will be carried out in each case. The evaluations will include not only the studies of the material characteristics post-forming but also the outcome of the forming itself.

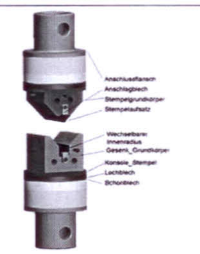
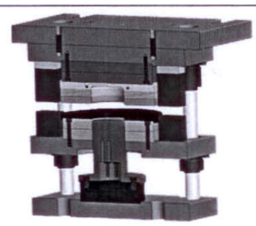
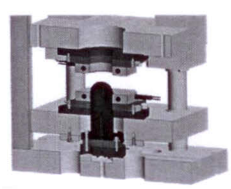
	Experiment tool	Parameters of experiment
Experiment of bending		Material: 22MnB5; 10MnCrMo8-3-2 Blank: Geometry: L 160 mm x B 80 mm Blank temperature: 800 °C, 750 °C, 700 °C, 650 °C, 600 °C Tool: Punch: R5 Matrix angel: 90° Tool temperature: max. 400 °C, 300 °C, 200 °C, 100 °C, RT
Experiment of cupping by Swift		Material: 22MnB5; 10MnCrMo8-3-2 Blank: Geometry: Ø 150 – 200 mm Blank temperature: 800 °C, 700 °C, 600 °C Tool: Punch: Ø 160 mm; 190 mm; 220 mm Tool temperature: max. 400 °C, 200 °C, RT
Experiments of stretch-forming		Material: 22MnB5; 10MnCrMo8-3-2 Blank: Geometry: L 200 mm x B 200 mm Blank temperature: 800 °C, 750 °C, 700 °C, 650 °C, 600 °C Tool: Punch: Ø 100 mm Tool temperature: max. 400 °C, 300 °C, 200 °C, 100 °C, RT

Fig. 12: Overview of the forming experiments

Here too the investigations focus on the formulation of different characteristics zones within the components. These are derived from the demands made of a structural component. The aim is thus to ensure that, based on the results of the material studies, it is specifically those variables that influence feasibility from a forming viewpoint that are examined.

The initial results not only affect the on-going FE simulations but also the design of the tools provided for creating demonstrator components. The demonstrators will feature geometries similar to those used in volume production with corresponding adaptations and sizing taking into account the results of the basic forming studies. Plans are underway for the construction of a technology section to examine the suitability of the whole of the process chain for volume production.

3.3.2 Incremental Forming (Roll Forming)

The characteristics determined in relation to the material form the basis for further studies into the technological development of roll forming and the combination of used processes. When it comes to configuring the technological process window, the first stage to be carried out is the FE simulation with subsequent verification of the results on the basis of experimental trials.

The structure of the tempered grading process will depend on the regulatory framework to which the final component will be subject. For instance, for the subsequent machining operations, such as trimming, a smooth component zone will be required in the flange area. In order to fulfil specific crash requirements, a defined arrangement of hardened and smooth areas is expedient. The overview in Fig. 13 shows the distribution of hardness that can, in principle, be achieved within the framework of a rolling profile from a quality viewpoint. For this corresponding system configurations are required.

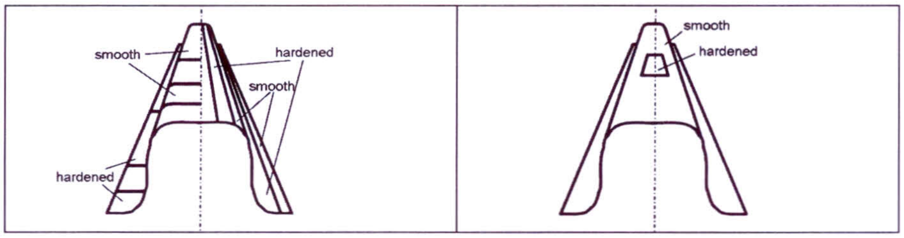


Fig. 13: Possible local structural improvements, hardening of tracks (left) and zones (right)

The formation of hardened areas in the direction of the rolling profile in zone hardening is likewise an object of study in the research project as well as hardening of tracks. At the same time the effects of reaction times and accuracies on the size and tolerance of the transition areas must be determined in accordance with the process management. Expenditure on the control system required to implement the requirements represents a major factor in the projected works.

The arrangement and alignment of the components for the heat treatment have a considerable effect on component quality (see Fig. 14). Siting the heat treatment between the first passes had proved expedient in established preliminary studies because the sheet is not yet formed. This is something which guarantees accessibility of both sides of the flat metal blank as well as the availability of the necessary space for the required components, depending on the heating strategy *[11]*. As far as this arrangement is concerned, it should be noted that it is not practical to temper component zones that are formed progressively and that this, by comparison to pure cold forming and subsequent heat treatment operations, means less design leeway in relation to the component. As far as any centralised arrangement of heat treatment in the installation between the passes is concerned, it needs to be examined whether enhanced contouring accuracy in relation to the component can be achieved in this way. Where heat treatment takes place at the outlet from the forming section, tempering of the overall profile is possible because no further forming is taking place. Practical trials are planned to determine the optimum arrangement of the heating facilities within the system.

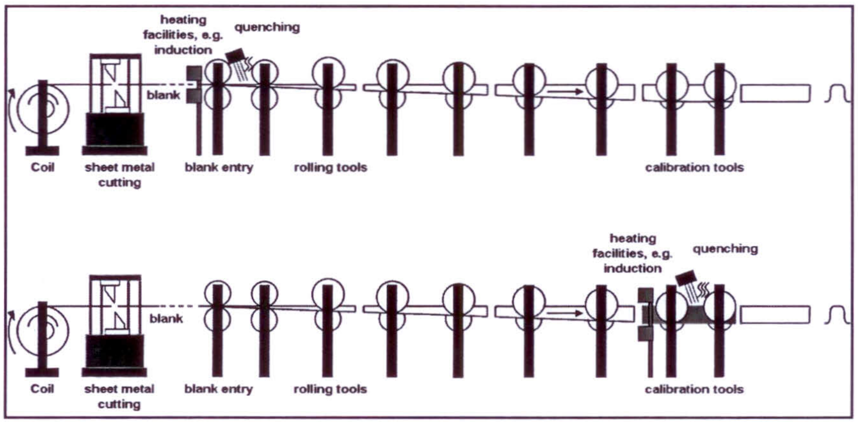


Fig. 14: Possible arrangements of heating facilities

As regards improvements to resource efficiency, precision analysis of the requirements profile in relation to a structural component for fabrication suggests itself with a view to localizing and more accurately defining the thermal influence zones required for tempering in terms of their cross-section and length.

A further focal point for study relates to the implementation of appropriate cooling strategies. At the same time, different concepts of medial cooling using air, oil or water right through to the use of cooled tools in quench hardening of the profiles are to be analysed and evaluated on the basis of energy-related considerations.

In conjunction with this, the necessary flexibility will be guaranteed by the modular structure of the apparatus required. The preferred location for quench hardening will be between two calibration rigs so as to keep the distortion to be anticipated in the profile to a minimum.

4 Summary / Outlook

There are forecasts that predict that the future will see an increase in the use of press-hardened structural components. The adoption of new approaches to optimising the structuring of process chains in hot sheet metal forming can thus make a valuable contribution to meeting the demands made by the customer, by politics and the manufacturer himself. The implementation of an effective approach to designing graded components means that different characteristics zones in the material can be formulated to cater for the individual loadings.

There are various ways of introducing graded characteristics into the component. The research approach adopted by this project lies in specific temperature management because a high degree of potential in terms of energy efficiency is not only evident in relation to productive implementation, but savings in costs are also possible. The aim is to increase process reliability, to fulfil the technological requirements and to achieve a high level of productivity.

The essential variables in this approach are heating, holding time, forming temperature, forming speed etc. Linking heat treatment with forming in a specifically designed tool makes it possible to formulate different temperature fields and thus to introduce grading into the structured component. Adopting this approach means that it is possible to dispense with an expensive downstream heat treatment for component grading, something which not only results in a shortening of the process chain but is more efficient from an energetic point of view.

The potential for energy saving lies, among other things, in the creation of relatively simple solutions (technically-speaking) that a high level of process reliability to be achieved. As a result of close cooperation with tool designers the results can be implemented promptly in production and any modifications agreed with those concerned so as to achieve the common aim of an energy- and resource-efficient layout of the process chain for hot sheet metal forming.

Bibliography

[1]	*Merklein, M.; Lechler J.: Investigation of the thermo-mechanical properties of hot stamping steels. In: Journal of Material Processing Technology, Volume 177, Issues 1-3, 2006, pp. 425-455*
[2]	*Bergmann, K.; Maikranz-Valentin, M.; Steinhoff, K.; Paar, U.: Verbessertes Festigkeits-/Dehnungsverhältnis durch modifizierte Wärmebehandlung höchstfester Vergütungsstähle vom Typ 22MnB5. In: Neuere Entwicklungen in der Blechumformung. 09. und 10. Mai 2006 in Leinfelden, Frankfurt/M.: MAT-INFO Werkstoff-Informationsgesellschaft, D, 2006, pp. 185-206*
[3]	*Liesner, J.; Marx, A.; Mebus, H.; Schaaf, S.; Stegmeyer, R.: Benchmarking anhand einer herstellerneutrale Referenzlösung. In: ATZ extra – Das InCar-Projekt von ThyssenKrupp, November 2009 58922, pp. 18-33*
[4]	*Neugebauer, R.; Sterzing, A.: Prozessgröße Temperatur – Warmumformung von Karosseriewerkstoffen 2005. In: 4. Chemnitzer Karosseriekolloquium, CBC 2005 (Hrsg.: Reimund Neugebauer), Chemnitz, D, 2005, pp. 155-170*
[5]	*Göschel, A.; Kunke, A.; Rautenstrauch, A.: Design of process chain for hot forming of high strength steels - state of the art and future challenges. In: Proceeding of COMA 2010, Competitive Manufacturing Conference : 3-5 February 2010, Stellenbosch, South Africa, 2010 ISBN: 978-0-7972-1322-7 pp.141-146*
[6]	*Maas, J.; Staudinger, W.: Tailored Blanks in der Warmumformung. In: ThyssenKrupp techform, D, 1/2008, pp. 29-31*
[7]	*Feuser, P.; Schweiker, T.: Tailored Temperated Parts – Presshärtbauteile mit maßgeschneiderten Eigenschaften. In: Tagungsband zum 4. Erlanger Workshop Warmblechumformung, Erlangen, D, 2009, pp. 127-142*
[8]	*Kuhn, D.: Scalight-Projekt - Neue Stahlwerkstoffe und Fertigungstechnik als Basis für den künftigen Automobilbau. MM Maschinenmarkt Das Industrie Portal www.maschinenmarkt.vogel.de 2010-03*
[9]	*DE 102 08 216 C1 - Verfahren zur Herstellung eines metallischen Bauteils, Benteler Automobiltechnik GmbH, Patentschrift, 27.03.2003*

[10]	*DE 197 43 802 C2 - Verfahren zur Herstellung eines metallischen Formbauteils, Benteler AG, Patentschrift, 14.09.2000*
[11]	*DE102004046119A1 - Einteiliges, durch Umformung hergestelltes Blechhalbzeug und Verfahren zur Herstellung eines Blechhalbzeuges, Universität Kassel, Patentschrift, 06.04.2006*
[12]	*Components with Optimised Properties due to Advanced Thermo-mechanical Process Strategies in Hot Sheet Metal Forming. steel research int. 79 (2008) No. 2*
[13]	*Neuere Entwicklungen zur Umformung höchstfester Stahlwerkstoffe. EFB-Kolloquium 2005, Dr.-Ing. Merklein, M.; Pitz, M; Hoff, C.; et al.; Universität Erlangen-Nürnberg*
[14]	*Larrañaga, J.; Galdos, L.; Geometrical accuracy improvement of flexibly roll formed profiles by means of local heating. 1st International Congress on Roll Forming: RollFORM´09, 2009, 17-24*
[15]	*Hoff, C.: Untersuchung der Prozesseinflussgrößen beim Presshärten des höchstfesten Vergütungsstahls 22MnB5. In: Geiger, M; Feldmann, K. (Hrsg.): reihe Fertigungstechnik Erlangen. Band 193, Bamberg: Meisenbach-Verlag 2008*
[16]	*[Source: Patent DE 10 2007 043 154 A1, Lengauer, G.; Schieder, A. H. A. e. a., Verfahren und Vorrichtung zum Härten von Profilen; 2007]*
[17]	*Bröckerhoff, M.; Wallentowitz, H.; Abratis, C.: Strukturverbesserungen für den seitlichen Pfahlaufprall - Structure improvements concerning side-on pole impact. In: 14. Aachener Kolloquium Fahrzeug- und Motorentechnik 2005 1, Aachen, D, S.*
[18]	*Steinhoff, K.; Saba, N.; Maikranz-Valentin, M.; Weidig, U.: Optimized processes and products in hot sheet metal forming. In: Proceeding of the 2nd International Conference Hot Sheet Metal Forming of High-Performance Steel CHS², 2009, Lulea, Schweden, pp.29-42*
[19]	*Stöferle, T.; Spur, G.: Handbuch der Fertigungstechnik Band 4/2. Carl Hanser Verlag München Wien 1987 ISBN 3-446-14954-6*