Manufacturing Flexibilisation of Metal Forming Components by Tailored Blanks

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Abstract
The automotive industry is continuously striving to reduce the energy consumption with lightweight constructions. In addition to a good automation the flexibility of the production process is very important for the car manufacturers. A lightweight technology must meet both criteria, namely being well automated and flexible as well. Flexibly produced tailored blanks are able to fulfill these requirements. An improved formability and an increased robustness of the manufacturing process can be achieved by targeted and local adaptation of the sheet thickness or mechanical properties. In this article innovative approaches are summarized that allow a more flexible production of tailored blanks and thus contribute to the flexibility of the entire metal forming process chain. In particular, the laser assisted tailored heat treatment offers the possibility to flexibly customize the mechanical properties and optimize them for the succeeding forming process. This paper reviews the manufacturing flexibilisation of metal forming components by tailored blanks.

Keywords
Tailored Welded Blanks, Patchwork Blanks, Tailored Rolled Blanks, Tailored Heat Treated Blanks

1 INTRODUCTION
Flexibilisation is defined as the relaxation or rather solution of solidified structures. This solution constitutes an important approach to meet increased demands in modern metal forming work. For a long time automotive industry is faced with diverging challenges, which are very hard to bring into harmony with each other. On the one hand, the raised requirements of the customers and the lawmaker have to be stated for more economical and ecological vehicles. [1] On the other hand, increased demands for comfort, interior equipment, safety and quality exist. Besides an improvement of engines, particularly the weight reduction of the vehicles displays a possibility with good prospects to solve this objectives’ conflict. In this context the use of lightweight materials such as aluminium alloys or high-and ultrahigh-strength steels appears very promising. However, in comparison to conventional deep drawing steels they have significantly lower forming limits and are therefore unable to comply easily nowadays with complex design requirements for automobiles. Because of this currently numerous approaches to expand forming limits in the fields of material, tooling, and tribology process are investigated. While under laboratory conditions promising results have already been achieved, apparently an application is difficult under close-to-production conditions for many technologies. On the one hand, a high degree of automation has to be guaranteed to withstand the competitive constraints and financial pressure. On the other hand, the manufacturers are increasing the variety of models trying to meet the individual demands of their customers. For this reason, a lightweight technology has to meet both criteria. It has to be both automated and flexible. A promising way to meet these requirements in metal forming equipment is the use of process optimized semi-finished products. [2] Through targeted and local adjustment of the sheet thickness or mechanical properties, formability can be improved, which implicates an increase in robustness of the manufacturing process, or new and innovative vehicle designs can be implemented.

In this article, innovative approaches are presented that allow a more flexible production of tailored blanks and thereby contribute to the flexibilisation of the entire metal forming process chain. On the one hand, the flexible production of custom-rolled sheet is the main objective. On the other hand, the innovative process of Tailored Heat Treated Blanks should be presented.

Figure 1 - Classification of tailored blanks
2 TAILORED BLANKS
A future-oriented kind of semi-finished sheet metal are the so-called tailored blanks. [2] These are semi-finished products, which hold customized characteristics for the corresponding subsequent forming station or for later use. Tailored blanks can be even further divided into patchwork blanks, tailored welded blanks, tailored rolled blanks and tailored heat treated blanks (Fig. 1).

2.1 Tailored Welded Blanks
Tailored Welded Blanks are the most widely used custom-made semi-finished products among these four types. Its specific feature is that different shapes are connected. They are characterised by the fact that they can combine different chemical composition, blank thickness, surface finish and/or mechanical properties. [2, 3] The various components are finally connected with the aid of a suitable joining method which is often the laser beam welding or mash-seam welding. By the use of a clever selection and positioning of the parts both the forming properties and the subsequent applications are improved. In addition, through the integration of different functions in one component the use of additional parts can be set aside. A particularly interesting aspect is the use of tailored blanks in crash-relevant components, such as a B-pillar. A softer, lower-lying area absorbs the crash energy, while a higher-lying part with high strength and stiffness protects the occupants of the vehicle.

Nowadays, these tailored blanks can even be used in complex metal forming processes, such as the press hardening. [4] Furthermore, applications in the hydroforming process are known in which the controlled use of tailor welded blanks have been improved by the productivity of secondary design elements. [5] The challenge in using tailored welded blanks lies in the consideration of the positioning of the weld seam. Generally, care should be taken to ensure that the weld is placed in non-critical areas of transformation. Through an extensive characterization of the weld using an advanced material characterization [6], the effects of the heat-affected zone, which occurs adjacent to the joint, can be well simulated. Several studies have shown that - improved by a non-linear design of the welding seams - the material flow during forming and thereby the sheet thickness could be reduced. [7] The technology of tailored welded blanks is now well understood and is already used in mass production in the automotive industry for many components. [8] A major disadvantage of the technology is on the one hand the high time and effort of producing and subsequent joining of the semi-finished products. On the other hand, the weld seam leads to challenges with respect to the heat affected zone, corrosion protection and optical surface quality.

2.2 Patchwork Blanks (PB)
Basically, Tailored Welded Blanks are similar to the so-called patchwork blanks. The blanks, which are also manufactured by joining operations, are characterized by being reinforced in particular areas with other blanks [9]. The two sheets are not joined like the tailored welded blanks with a butt joint, but with an overlap joint. This provides two essential benefits: On the one hand, the main blank does not have to be recessed so the produced cutting can be reduced. On the other hand, a lower shape accuracy of the two joint partners is accepted because a fitting is not required. [10] The advantages of patchwork blanks make it a clearly more flexible process and also allow the production of complex geometries, due to the fact that it is possible to place reinforcements in small areas. Even with these customized semi-finished products the used joining process plays an important role. Most laser or spot welding processes are used due to their good automation. With the former joining process a media-tight connection can be put into effect in terms of better corrosion protection.

The design of the weld seam plays a key role in the implementation of the technology and is therefore the subject of numerous analyses. But in contrast to tailored welded blanks the plane joint between the joining partners provides the additional benefit of using an adhesive bond. [11] As a consequence, there are no negative effects from heat affected zones and it is possible to join materials with strongly different melting points. Moreover, the adhesive joint has vibration-reducing potential.

Patchwork blanks have been used in mass production at several automotive manufacturers. Similarly, their potential to extend the forming limits in the hydroforming process have been proved. [5]

2.3 Tailored Rolled Blanks (TRB)
As third group, the flexibly rolled semi-finished products can be referred. These Tailored Rolled Blanks in contrast to Tailored Welded Blanks and Patchwork Blanks are not manufactured by a joining process, but by a forming process. [12] As mentioned above, attention has to be paid to the weld seam and the resulting heat affected zone because this may represent the weak point in the forming process or the subsequent application. Abrupt changes of mechanical properties and abrupt transitions of sheet thickness can be prevented with TRBs and allow a better material flow without a notch effect. Tailored rolled blanks are produced by a rolling process with a continuous change of the roll gap. Through the displacement of the material the produced blanks can be used optimal in manners of lightweight construction without any waste. [13] Furthermore, the metal forming manufacturing of Tailored Rolled Blanks is also dimensionally accurate, inexpensive and flexible. By combining various rolling methods, not only a plane, but also a spatial layout of the blanks is possible. Moreover,
tubes and profiles are also produced with varying material thickness. TRBs are especially further processed by deep drawing or hydroforming and are already used in series production. [14]

As part of the SFB TR 73 currently new approaches for the production of tailor-made plates with different thicknesses are investigated. Through a combination of processes from the sheet metal forming and massive forming, it is possible to produce complex geometries. It has been shown that by alternative manufacturing processes, such as compressing or wobbling, also TRB-like sheets can be produced. [15, 16].

2.4 Tailored Heat Treated Blanks

Based on the idea of making the production of tailored blanks more flexible, a lot of work in the field of Tailored Heat Treated Blanks was performed especially in the last years. [17] The Blanks have local different mechanical properties optimized for the succeeding sheet metal forming process. The strength distribution is obtained by a partial heat treatment, which is performed before the actual forming operation. [18] In comparison to conventional temperature assisted processes the forming can be performed at room temperature with a conventional forming tool. For the successful application of Tailored Heat Treated Blanks several conditions must be fulfilled. First, it should be possible to change the mechanical properties of the semi-finished material significantly by the heat treatment. The strength should be increased or lowered by the heat treatment. However, a complete heat treatment would not lead to an increase of formability. This is rather based on the interaction of hard and softened areas and a resulting, optimized material flow. Second, a local heat treatment should be possible. A local heat treatment is especially easy, if the heat treatment time is very short, the maximum temperature is low and the thermal conductivity is not too high. Based on this technological axioms several scientific investigations were performed.

The first basic research on this technology has been carried out by Siebel and Beisswänger in 1953 [19]. As part of their analysis, they used steel (S18, V2AE), brass (CuZn37), aluminium (Al 99.7) and nickel silver. The materials were at first hardened by rolling operation. Subsequently, they partially annealed the blank with a welding torch, whereby recrystallizations effects were realized. Although a significant increase of the limiting drawing ratio could be achieved, the technology has found no way in industrial practice because of the complex process control and non-robust heat treatment.

Although there were research projects for copper as well, the further scientific investigations concentrated on steel and aluminum for the application of Tailored Heat Treated Blanks.

2.4.1 THTB with steel materials

Softening

A significant reduction in hardness of high-strength steel materials is shown by Neugebauer et al. [20] and Weisheit et al. [21]. They identified structural transformations as a cause for the change of the mechanical properties. For dual phase, complex phase and TRIP steels, the drop in hardness is lower. Except for the TRIP steel at investigated materials showed a reduction of yield and tensile strength and an increase of the uniform elongation. However, heat treatment leads to significant distortion. The potential of the technology was proved for the demo parts, where a significant reduction of the necessary forming force was detectable. Moreover, a pillar can be produced without failure with this technology. However, the high distortion and the poor understanding of the correlation between time-temperature-history and microstructure are challenges for further scientific investigations. In [22] it was attempted to soften high and ultrahigh-strength steels and then to harden them after forming again. The research activities showed previously that for a softening temperatures above 723 °C (Ac1) must be achieved. In addition, it was possible to simulate the processes. Schuöcker showed in [23] that a local softening is not only possible before, but also between two forming stations. He uses recovery and recrystallization effects. Demonstration example was a multi-stage hydroforming process.

Hardening

Besides softening, also several research projects concentrated on the local hardening of the material Hillebrand showed in [24] the partial hardening of bake-hardening steel with the help of a diode laser. This effect is normally used by the automotive industry within the cathodic dip-paint coating. He investigated the bake-hardening steel ZStE 180 BH. In addition to the hardening of security-relevant parts a reduction of springback could be achieved. Palkowski examined in his research hardening in dependency of the time-temperature profile and the pre-forming. [25] In [26] the design of the heat treatment layout was optimized with the help of a simulation. By a locally based heat treatment of preformed material Reimche could set in [27] anisotropic strength and deformation properties and thereby influence the crack propagation. In [28] the process was performed using a local solidification structure of the board, the plastic deformation behavior of complex components and controls that achieved an extension of the forming limits. The entire process was also calculated in a simulation.

2.4.2 THTB with aluminum alloys

For not heat treatable aluminum alloys Hogg and Liewald have shown in [29] that a local softening of the material is possible. For this, however, a solution annealed state has to be achieved, which requires a holding period of about 30s and a temperature of about 500°C to 540°C. For the same group of
materials a softening in multi-stage forming processes is also possible. The high holding period and temperature requires the use of heat treatment methods based on heat conduction and induction, which are in [30] the investigations’ subject.

Precipitation hardenable aluminum alloys are, in particular, suitable for the production THTB. These alloys are used in different application areas as rolling, extrusion, forging and casting products. Their main alloying elements are magnesium and silicon. As part of the manufacturing process, these alloys are first cold rolled and then for about an hour solution annealed at temperatures of 470°C to 560°C. [31] By a subsequent rapid cooling to room temperature, a supersaturated solid solution arises with the alloying elements magnesium and silicon. Already in 1941 Haase found out that a short term heat treatment can be used to soften the material again. [32] The strength increasing MgSi-Clusters were dissolved, which leads to a quasi solution annealed state (Fig. 2).

![Figure 2 - Schematic principle of the THTB technology](image)

For the heat treatment of aluminum alloys different methods based on heat conduction, heat induction and radiation can be used. The advantages of induction and conduction are the very short heat times, because the complete heat treatment areas can be heat treated within in one step. Moreover, a homogeneous heat treatment is possible. In contrast a robot controlled laser system has a very high flexibility in combination with a short set-up time and is therefore, in particular, useful for research, prototype and small series with a wide range of variants. With the laser technology the energy coupling takes place only at one side of the blank. Nevertheless, for sheet thickness below 1.5mm a homogeneous and sudden heating is possible. At the Institute of Manufacturing Technology (LFT) a Nd:YAG laser with a maximum power of 4 kW and an Gaussian profile was used. With a wavelength of 10.6 μm a fairly good absorption by the aluminium is possible. By using a CO₂-laser an additional coating of the material is necessary in order to increase absorption and to realize an efficient process. Investigations from [33] showed that the maximum temperature is the most important parameter to influence the mechanical properties of AlMgSi-alloys. The cooling rate has nearly no influence.

The biggest challenge for the successful production of Tailored Heat Treated Blanks is the positioning of hard and soft areas. By the interaction of the zones the material flow can be influenced and improved. A softening alone would not enhance the formability. The methodically design of the heat treatment layout was the subject of many investigations. For simple cylindric cups an analytical approach was developed. [18] For more complex geometries thermo-mechanical-coupled simulations based on the finite-element-method were built. These were used to design heat treatment layouts and to test their effectiveness. The procedure was evaluated by the pressing of demo parts. Based on the results, universal design principles for heat treatment layouts were derived. [34] Additionally, at the Institute of Manufacturing Technology, a new approach was developed for the determination of soft and hard areas. Based on the analysis of non-heat-treated blanks a suitable strength distribution and corresponding laser heat treatment was defined (Fig. 3). [35]

![Figure 3 - Inverse approach for the design of THTB technology](image)

Newer research works investigate the THTB technology for further metal forming operations. In [36] the improvement of the roll hemming process by local heat treatment is analysed. Moreover, it could be shown that fast hardenable aluminum alloys can not only be softened, but hardened by short term heat treatment as well. [37] By the combination of the accumulative roll bonding process and the local heat treatment a gradient along the sheet plane and thickness is possible [38]. Finally, the heat treatment is not only possible before the forming process, but also between two forming operations and can be applied to profiles.

All scientific investigations have shown that a local heat treatment can be used to enhance the formability of the material and consequently the robustness of the production process. The application allows a more flexible design of metal forming processes. In particular, for materials with a limited formability like aluminium alloys or high strength steel facilitate long-range applicabilities. In comparison to conventional semi-finished products higher deep drawing ratios, smaller radii and more
complex geometries can be manufactured. Thereby the flexibility of the material is enhanced.

3 SUMMARY
The manufacturing flexibilisation of metal forming products represents a challenge for the automotive industry, in particular, in view of present trends to lightweight constructions. Several modern production technologies limit the flexibility of the processes. Tailored blanks provide the possibility to enhance the formability of lightweight materials and at the same time ensure flexibility. In this context THTB are of particular interest. By a flexible, local heat treatment before the forming process a tailored property profile can be created. Especially suitable for the application are aluminum alloys of the 6000-series. By a shock heat treatment the strength increasing precipitation can be dissolved. The technology was qualified for many geometries and developed ready for series production.

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