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MANUFACTURING OF SHEET METAL PARTS FROM TAILOR ROLLED BLANKS

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ABSTRACT

With respect to the preserving of ressources, lightweight construction and the application of new materials are becoming more and more important. This paper focuses on the manufacturing and processing of tailored products, i.e. Tailor Rolled Blanks (TRB). Their load optimised structure enables new approaches in lightweight construction. Contrary to the production of this kind of semi-finished products their further processing is still a challenging task. Investigation results of deep drawing and bending of Tailor Rolled Blanks with special emphasis on the avoidance of wrinkling and compensation of springback are presented. In addition to this, a new sheet forming process is described, which offers high potential especially towards prototyping and small series. Flexible CNC-controlled Incremental Sheet Forming is characterised by a systematical thinning of the processed areas with steep flanges. A combination of this process with dedicated blanks seems promising to obtain any kind of thickness distribution on the final product.

Keywords: tailored products; lightweight construction; incremental forming

INTRODUCTION

Lightweight construction is a design philosophy which aims at a maximum reduction of weight by the substitution of traditional materials by materials with low density (e.g. aluminium, magnesium) or by high-strength materials like special alloys or titanium.

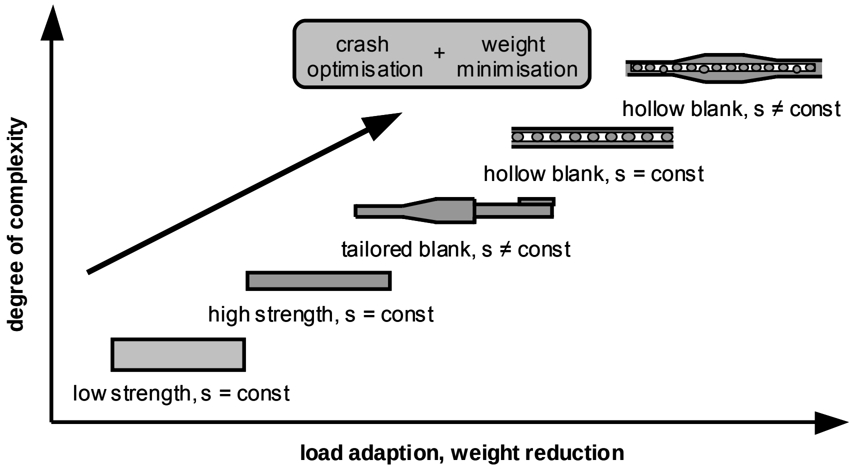


Figure 1: New sheet metal structures aiming for weight reduction

In the aerospace industry this design concept was established a long time ago and it is becoming more and more important also for other industrial sectors due to economical and ecological reasons [1]. The conservation of material ressources is one of the primary motivations for the therefore necessary efforts, but even more important is the reduction of energy consumption by the use of lighter vehicles. An impressive example is the influence of the vehicle's weight on the fuel efficiency. A saving of 100 kg of weight allows for a reduction of fuel consumption of about 0.5 liters every 100 km covered.

Unfortunately, light weight construction is often hard to achieve, because it will only be feasible if neither the safety of the product is affected nor the production costs are compromised. Some possible approaches aiming for light weight construction are illustrated in Figure 1. Starting with traditional blanks having a constant sheet thickness but made of material with lower density and/or higher strength, the load adaption can be improved with a certain increase of the part's complexity. A step further towards load adaption is done by blanks with a non-uniform thickness profile, like e.g. Tailor Welded Blanks (TWB), Patchworked Blanks or Tailor Rolled Blanks (TRB). Finally, hollow blanks with or without load adapted sheet thickness allow for a further, significant reduction of weight maintaining the required mechanical properties.

TAILOR ROLLED BLANKS (TRB)

The first attempts to use blanks with higher thickness only in areas where high loads are expected were done 20 years ago. In 1985 special blanks for the bottom of the Audi 100 could not be obtained in the necessary dimensions. Therefore Audi joined blanks with different thicknesses by welding [2]. These blanks are nowadays well known as "Tailor Welded Blanks" (TWB) and were used in 1991 by Volkswagen in series production for lightweight optimisation [3], [4]. The advantage is that in areas with lower loads material and thus weight can be saved. But there are also some disadvantages. Many times, the seams cannot be placed at positions which are beneficial for weight optimisation. Due to the change of material properties in the thermal influence zone, they have to be located in areas convenient for further processing with subcritical deformations. In addition to that, a transverse movement of welded blanks with different sheet thicknesses during deep drawing is disadvantageous and the abrasion of the tools is increasing significantly.

More recently, the alternative of Tailor Rolled Blanks was developed at the Institute of Metal Forming (IBF), RWTH Aachen. These blanks with longitudinal thickness transitions are produced by a controlled online adjustment of the roll gap [5]. The thickness of the blank coming out of the roll gap is measured directly. An integrated algorithm performs a closed-loop control of the desired sheet thickness and accordingly adapts the clearance between the rolls. In industrial scale production, the company Muhr & Bender (Mubea) nowadays is able to guarantee an accuracy of ±0.05 mm in thickness direction (Figure 2, left hand side).

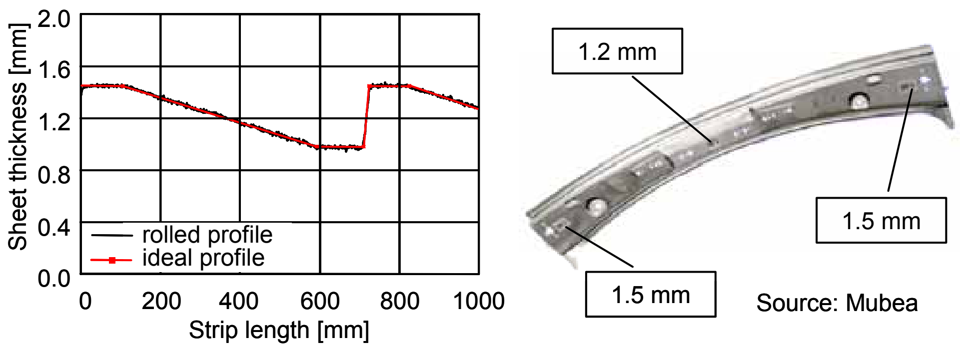


Figure 2: Deviation control of a TRB (left) and automotive application (right)

The achievable transition slope is a function of the rolling speed. Today, the most economic transition slope is stated with 1:100, which means 1 mm thickness difference over a length of 100 mm. However, production costs do not depend on the number of thickness transitions. The final product is a load adapted Tailor Rolled Blank, for which many applications have already been found, especially in the automotive industry (Figure 2, right hand side). Recently, a new plant for the production of TRBs was built up at Mubea in Attendorn, Germany. Altogether, Mubea delivered 2.5 million TRBs so far and is capable today producing 70,000 tons per year of TRBs with a width up to 750 mm. The industrial process route envolves heat treatment as well as surface coating. This allows for an adjustment of material properties within a wide range (Figure 3).

In summary, Tailor Rolled Blanks have the following advantages and disadvantages:

- Production costs of TRBs do not depend on the number of thickness transitions
- Within the process limits any thickness transitions can be choosen and adapted exactly to the required load of the product in use
- Because of the smooth thickness transitions, there are no stress peaks across the transition when the part is loaded
- Very good forming properties because of the elimination of welding seams and corresponding heat-affected zones in TRBs
- With a special heat treatment after flexible rolling and different material properties in the flexible rolled blank can be adjusted.

- Only blanks with longitudinal transitions can be produced [6]
- Only blanks with widths up to 750 mm are producible today.

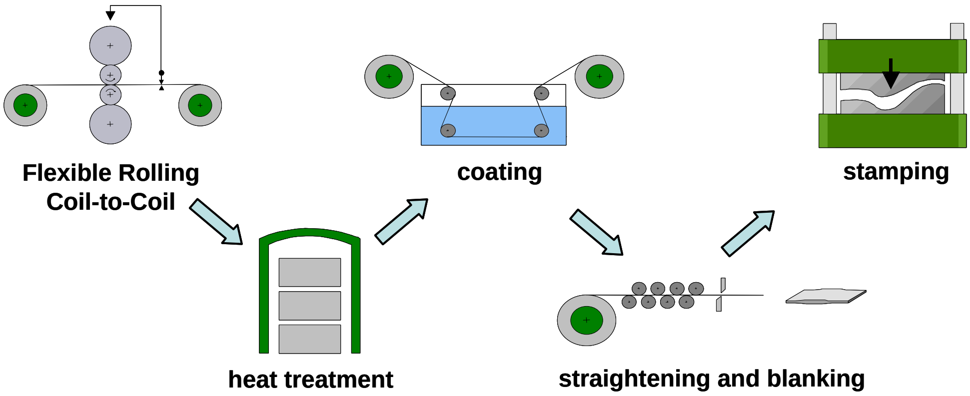


Figure 3: Process Chain for the production of TRBs

FURTHER PROCESSING OF TAILOR ROLLED BLANKS

Knowing how to produce flexibly rolled blanks with thickness transitions in longitudinal direction is only a first step. The next step is to examine the behavior of these products in further processings.

4.1 Deep Drawing

In this chapter, two practical investigations aiming for a basic analysis of the behaviour of TRBs while deep drawing are presented. In all tests the same tool setup as displayed on the right side of Figure 4 was used. The blankholder set was combinable with different blankholder adapters in order to allow testing TRBs with different thickness transitions.

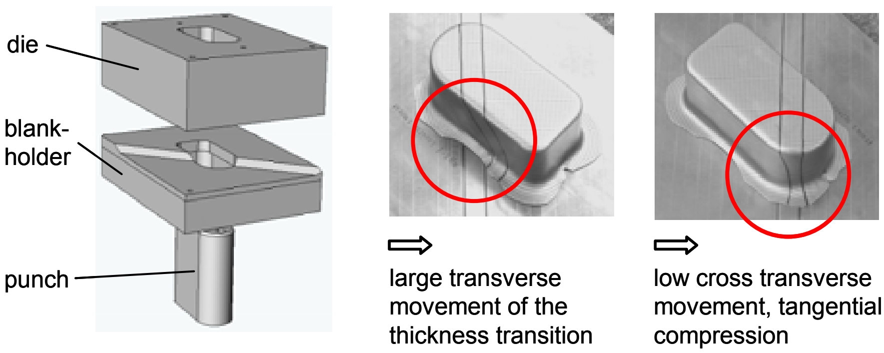


Figure 4: Deep drawing test with a Tailor Rolled Blank. Only the blankholder is adapted to the thickness transition of the blank [6]

In the first test series, the solid blankholder adapter has been fitted to the diagonal thickness transition of the TRB. The applied TRBs were all made of DC04 and had a thickness of 1.1 mm in the thinner and a thickness of 1.6 mm in the thicker area. The transition lengths were 20 mm, 80 mm and 300 mm. For an easier identification, the transition areas of the blanks, which all are oriented in the same defined direction across the die, have been marked with two black lines. Analysing the boundaries of the thinner areas after deformation, a large transverse movement can be observed as well as tangential compression in the area of the corner radius (Figure 4, right hand side). Next to that, wrinkles are observed depending on the transition length [6].

During the tests at the IBF, significant influences for the creation of wrinkles in the flange could be evaluated:

- Short transition lengths like in this case 0.5 mm thickness reduction within 20 mm (Figure 5, top) lead to sections of high wrinkling. If the transition moves towards the thinner area of the flexibly rolled blank, the blankholder is lifted. The outcome is a loss of contact between blank and blankholder, which leads to the formation of wrinkles. There is also loss of contact, if the blank moves into the other direction. This also causes local wrinkling in the section without contact in the transition area.
- Increasing the transition length to 80 mm and maintaining the reduction of 0.5 mm (Figure 5, middle), the formation of wrinkles can already be visibly reduced.
- If the whole flexibly rolled blank is a transition (Figure 5, bottom), the formation of wrinkles is inhibited totally. In this case there was a thickness difference of 0.5 mm as in the tests before, but now over a section length of 300 mm.

This is traced back to the fact that a cross transverse movement of the thickness transition leads to either lifting or withdrawing of the blankholder in all areas. As a result, surface pressure exists everywhere between blank and blankholder [6].

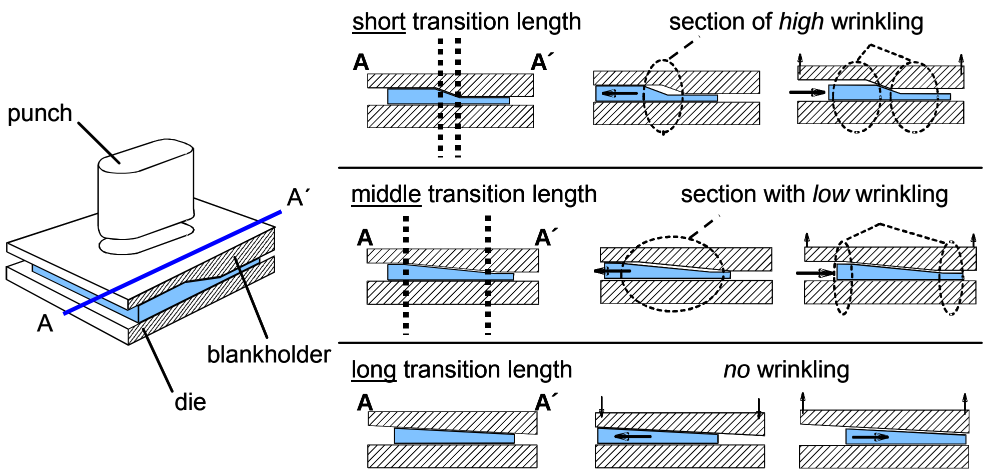


Figure 5: Deep drawing test on TRBs. Depending on the transition length wrinkles occur [6]

In order to prevent wrinkling during deep drawing of TRBs, the tool setup has been modified in the second test series. The solid blankholder adapter has been substituted by a multilayered, flexible blankholder system (Figure 6, left hand side). Between the solid blankholder set and the flexible polyurethane plate (10 mm thick) has been placed a plate compensating the thickness differences of the flexibly rolled blank. A quenched, 2 mm steel blank was put on top of the polyurethane plate in order to ensure a friction ratio comparable to the solid blankholder adaptions as well as to avoid excessive abrasion.

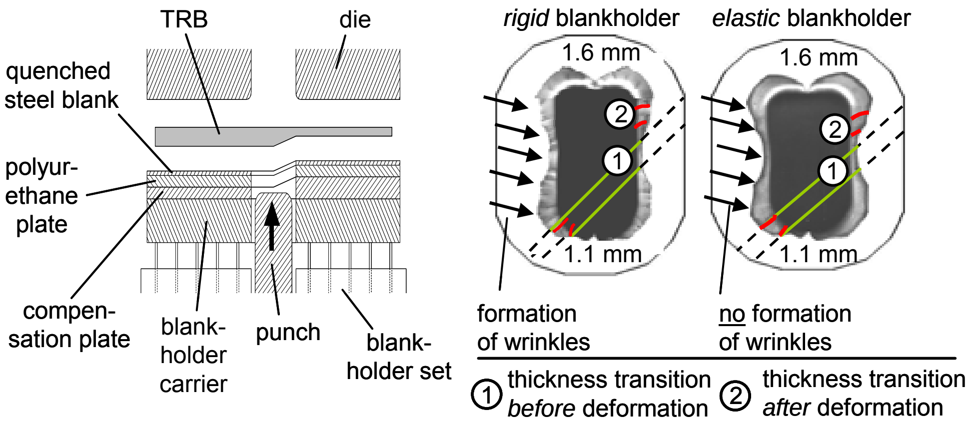


Figure 6: Deep drawing test on TRBs applying an elastic blankholder [6].

Using this elastic blankholder, also developed in several research laboratories [7], the formation of wrinkles could be reduced significantly, even when a disadvantageous configuration was used, i.e. a short transition length and a large cross transverse movement of the thickness transition [6].

In summary, the experiments proove that by the adaption of the blankholder to the particular sheet thickness profile, the occurrence of wrinkles can be reduced significantly. In the same way, those modifications allow for drawing depths comparable to conventional sheets.

4.2 Bending

In the area of sheet bending, two different process variants have to be distinguished: Air bending and die bending. Contrary to die bending, where the desired shape is transferred directly from the die to the part by coining, the resulting angle in case of air bending is determined by the position of the bending edges and by the part's geometry (Figure 7).

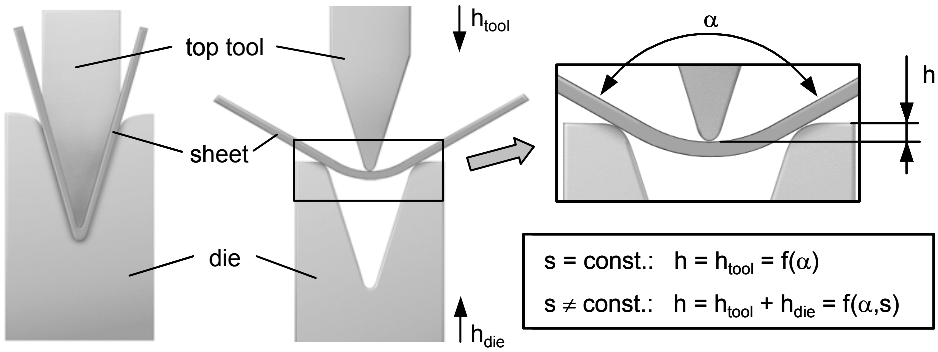
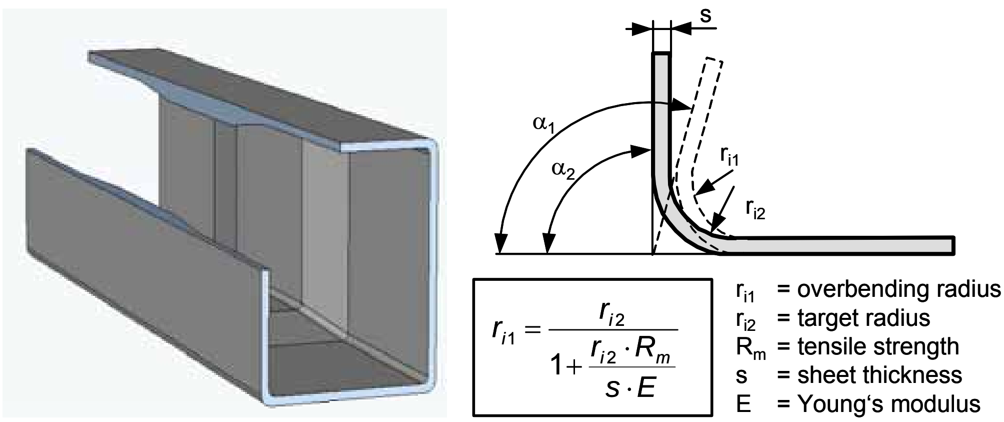


Figure 7: Process Principle of die bending (left) and air bending (right). Sheet thickness compensation by variation of die height

In both cases, the flow curve, the sheet thickness and the mechanical properties yield primary influence on the accuracy of the target angle. Due to the fact, that the edge profile of the die can be adapted arbitrarily to the sheet thickness profile, die bending is an ideal process for the production of profiles out of Tailor Rolled Blanks. In order to end up with a uniform angle along the bending edge, it is necessary to compensate the locally differing springback coefficient by overbending of the thinner sections of the sheet (Figure 8).



$$r_{i1} = \frac{r_{i2}}{1 + \frac{r_{i2} \cdot R_m}{s \cdot E}}$$

Figure 8: Orientation of thickness transition and influence on target angle

In the areas of transition, the die height is set gradually or inclined to ensure a maximum accuracy of the bending angle. The overbending of the thinner partitions is realised by lifting the dies (Figure 7). The lifting height is depending not only on the thickness difference but on the chosen material with its particular flow curve and mechanical properties also. This demands for the availability of the flow curves for every material and every applied thickness. Since systematics for the determination are lacking, the optimum height profile of the die has to be approximated by empirical testing.

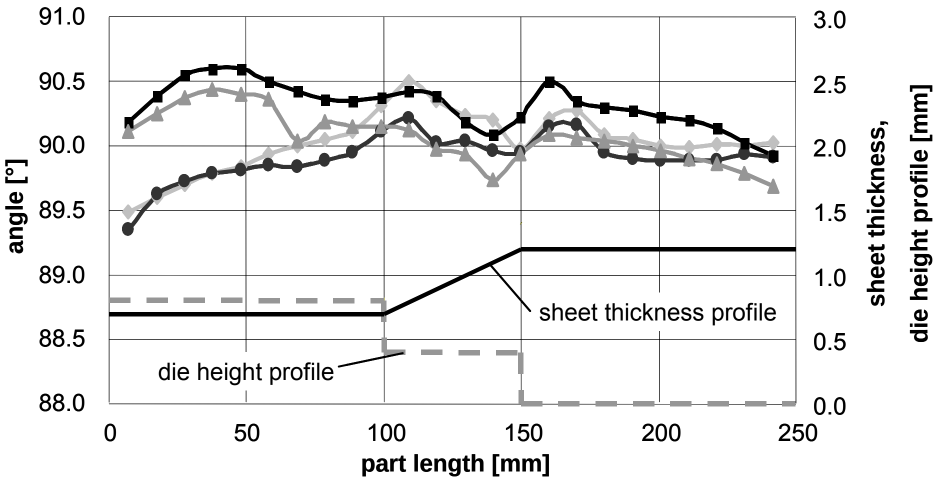


Figure 9: Angle profile of several specimens after air bending of a TRB

First experiments were carried out using blanks made of microalloyed steel (H340 LA) with a centric thickness transition of 0.5 mm at a transition length of 50 mm. The die height was adapted steplike to approximate the sheet thickness profile. Conducting several tests, it can be found, that the accuracy of the angle shows maximum deviations of about 0.7° and increases significantly with the sheet thickness (Figure 9). The curvatures observed especially in the thinner areas of the bended part are due to residual stresses caused by the rolling process, which are released while cutting the blanks. Even in case of constant sheet thickness a significant irregularity of the obtained angle can be found. Near transition areas, larger deviations occur in negative and in positive direction as well. An explanation for this phenomenon is the unevenness of the used blanks in those areas. Air bending shows a pronounced sensitivity to any deviation of planarity, sheet thickness or material inhomogeneity.

4.3 CNC Incremental Sheet Forming

An interesting combination could be the processing of tailored blanks applying a new, flexible forming process which is especially suitable for the manufacturing of small lots and single copies of complex sheet metal parts [8], [9]. In CNC Incremental Sheet Forming (ISF), the shape of the desired part is obtained by the numerically controlled movement of a universal, ball headed punch. The support underneath the part to be formed could be realised by a simple tool post (Figure 10) or in case of complicated shapes with delicate corrugations by a full die. Because of the low forming forces occuring during the process, the dies can be made by milling out of tooling steel, aluminium, plastics and even wood. An important characteristic of the process is the small zone of plastic deformation which is restricted to the immediate vicinity of the forming head and thus is moving over the entire part during the process. In addition to the low forming forces this circumstance makes a material flow from the surrounding area into the forming zone impossible.

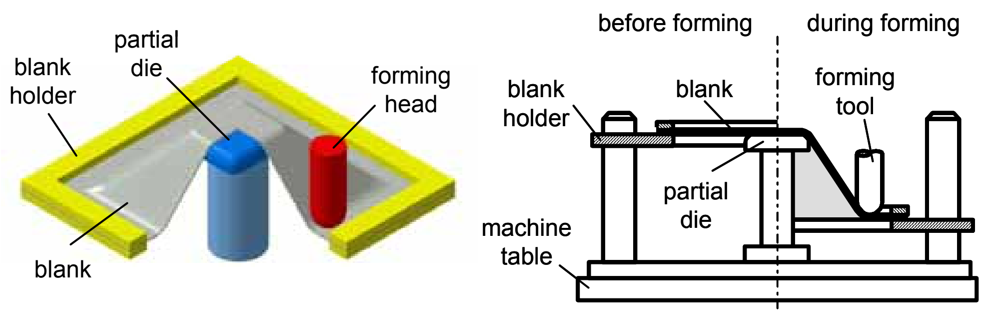


Figure 10: Process principle of ISF

Since the surface of the workpiece increases significantly during the manufacturing, the sheet thickness in the processed areas decreases due to the conservation of volume. In case of plane strain conditions, a formal description known as “sine-law” from the related spinning process can be validated (Figure11, right hand side):

$$t_1 = t_0 * \sin(90°-\alpha)$$

This means that depending on the material wall angles larger than 60° respectively 70° cannot be formed without the occurrence of explicit necking (Figure 11, left hand side) or even cracks [10]. In some cases the severe thinning of the sheet in steep areas of the workpiece can be overcome by special preforming operations or the application of a multistage forming strategy [11]. However, not only the restriction to relatively shallow shapes but also the significant inhomogeneity of the wall tickness profile is setting many limitations to the industrial application of the process so far.

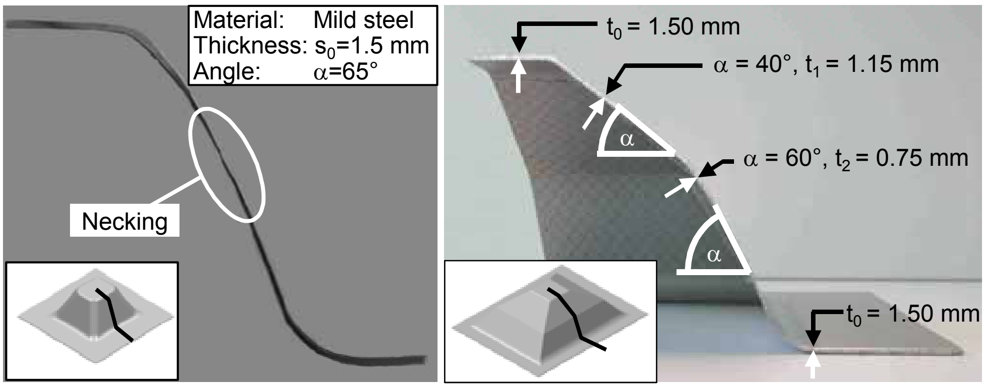


Figure 11: Necking at large wall angles (left) and effect of the sine-law (right)

Besides the possibilites concerning a strain-adapted design of workpieces, TRBs with a determined initial sheet thickness profile enable the manufacturing of workpieces with a more uniform thickness distribution or could offer more material reserve in areas with very steep wall angles. Therefore, tests were carried out aiming at a compensation of the thinning at steep angles by applying tailor rolled aluminium blanks with a sheet size of 320x250 mm. The blanks' initial sheet thickness of 1.95 mm was decreased to 1.26 mm in a 70 mm broad stripe in the middle of the blank by flexible rolling. The transition from the initial thickness to the thinner area is symmetric and is done within 20 mm on each side (Figure 12).

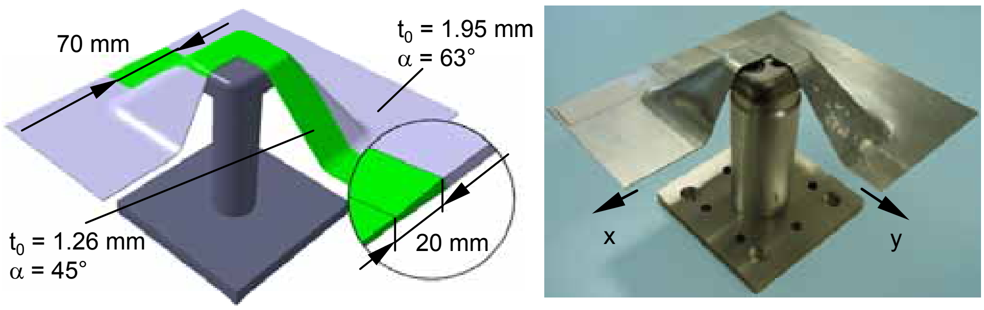


Figure 12: Experimental set-up and cut workpiece

As a test shape, a pyramidal frustrum as shown in Figure 12 was chosen. The use of a partial die which is only supporting the top surface of the pyramid allows for the manufacturing of flanges with arbitrary and different inclination. The sheet is clamped into the blankholder in such a way that the stripe of reduced initial thickness is congruent with the die (Figure 12). The inclination of the two flanges to be formed containing the flexibly rolled area was set to an intermediate value of 45°. Applying the sine law and aiming at a homogeneous wall thickness profile on the formed part this results in a target wall angle of about 63° in the areas with higher original sheet thickness. After the forming process, the workpiece was cut and the resulting sheet thickness has been measured using a micrometer gauge in sections along the thin stripe (y) and additionally in the perpendicular direction (x). After a short transition distance at both ends, the thickness profile shows constant and almost homogeneous values along the entire flanges of the pyramid.

Predominantly, the calculated value determined by the sine-law, about 0.89 mm, is met (Figure 13).

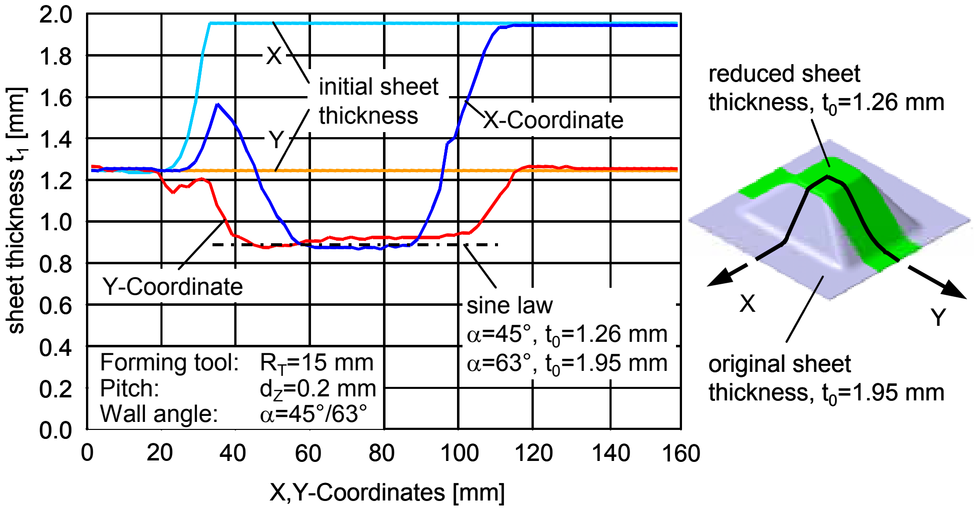


Figure 13: Wall thickness profile of an incrementally formed tailored blank

The application of TRBs to incremental sheet forming reveals a vast potential of this combination consisting in a flexible forming process and an especially adapted blank. So far, this approach is limited to regular geometries, but yet shows the principle possibility to manufacture parts with homogeneous thickness profiles at least along plane flanges. Doing so, the cumulation of redundant material can be effectively avoided while meeting the requirements to sheet thickness and material properties. The contributions of ISF to lightweight construction due to its high achievable strains in comparison to traditional forming processes can be significantly increased by the use of especially prepared blanks.

CONCLUSION AND OUTLOOK

With regard to the saving of energy and ressources, light weight construction has become a main goal especially in the area of vehicle construction. Since the design of Tailored Sheet Components can be adapted to the expected loads, these products show great potential concerning weight reduction. Once tools and equipment are adjusted to the non-conventional thickness profile, processing steps like deep drawing and bending become more reliable and accurate. In this context, TRBs can enable higher drawing depths than TWBs and thus enhance the range of possible applications. A new promising development could be the combination of the two rolling processes to obtain thickness distribution in two directions. Such a blank with a biaxial thickness profile would offer the same potential concerning weight reduction as Patchwork Blanks without the disadvantages of welding seams. The higher formability obtained this way could lead to a further increase of the application area.

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IZRADA DELOVA OD "TAILOR" VALJANIH LIMOVA

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REZIME

Koncept lakih konstrukcija zbog očuvanja prirodnih resursa (materijala) postaje sve važniji u mašinstvu. Primena novih materijala u konceptu lakih konstrukcija je jedan od ključnih faktora razvoja. Ovaj rad fokusiran je na izradu i dalju preradu "tailored" limova - TRB (specijalno proizvedenih i iskrojenih limova). Njihova struktura koja je optimirana obzirom na opterećenje pruža sasvim nove mogućnosti u konstrukciji delova, sklopova i kompletnih proizvoda. Sama proizvodnja te specifične vrste limova je postala praksa u razvijenim industrijama ali njihovoj daljoj preradi još uvek nisu definisani sve parametri procesa. U ovom radu dat je prikaz ekperimentalnih istraživanja procesa savijanja i dubokog izvlačenja takvih limova, sa težistem na analizi opasnosti nastanka naboravanja u oblasti venca kao i sa stanovišta elastičnog vraćanja lima. Pored toga prikazan je i novi proces deformacije lima koji omogućava postizanje velike efektivnosti, pogotovu u oblasti malih serija i prototipova. Taj proces baziran je na CNC-inkrementalnom pristupu sistematičnog stanjivanja lima. Proces omogućava izradu delova sa promenljivom debljinom zida po celoj konturi obratka.