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LOCALLY REINFORCED HYDRO BONDED BLANKS

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ABSTRACT

Locally reinforced sheet metal parts can be used as a contribution to lightweight construction. They can also help to enable a load-adapted way of constructing parts or machines. One possibility to produce locally reinforced parts is the Bonded Blanks technology, where base sheets are locally joined with reinforcement-sheets by adhesive bonding in two stages and formed together in just one forming operation. The joining-step of the base sheet with its reinforcing sheet is followed by forming of this bonded double layer by deep drawing. The final curing process is initiated by heat-treatment during drying-step in cataphoretic coating.
This paper deals with the investigation on the effects of hydromechanically deep-drawn parts with local reinforcements produced with the Bonded Blanks technology. Different sheet metal materials along with different adhesives are tested.

Key words: *Bonded blanks, hydro-mechanical deep-drawning*

1. INTRODUCTION

The Automotive industry faces rising demands on vehicles comfort, driving performance and passenger safety as well as on the aspects of environmentally friendliness and resource efficiency. As results the reduction of fuel-consumption and improvement of recyclability were enhanced continuously over the years. But one of the biggest challenges still remains in the need to reduce production costs. Lightweight construction uses the capability of (new or improved) materials as well as the advantages resulting from innovative production technologies and vehicle concepts. Examples for these are Tailored Blanks, Patchwork and also Bonded Blanks technology [1, 2].

Bonded Blanks are locally reinforced sheet metal blanks in which defined areas are getting strengthened by the use of reinforcing sheets. These sheets are characterized by different sheet thicknesses or different steel grades in comparison to the base sheet they are applicated on. A combination of both characteristics is possible as well. The base and the reinforcing sheet are formed together in just one forming operation. During forming, a relative movement between the two sheets is possible by means of sliding. This enables a freely plastic forming of both components. A pre-joining (as fixation) to ensure the parts being located in the right way when going into the forming process is necessary [2]. The adhesive bonding for fixation may offer enough stabilization to join the parts, otherwise the fixation by an additional joining operation like welding or fixation by pins might be necessary. The final joining of base and reinforcing sheet proceeds after the forming operation is completed. This could be initiated by heat for instance in the drying step of cataphoretic coating. All above mentioned process steps can easily be integrated into established production process chains. This is very important in avoidance of generating new additional production costs by using this technology.

2. LOCAL REINFORCEMENTS IN SHEET METAL PARTS

Locally reinforced sheet metal parts can be used as an effective contribution to lightweight construction. They can also be used to enable a load-adapted way of constructing parts or machines. There are different methods to reinforce local areas of sheet metal parts as shown in *Fig.1*, where the example of a strut-support geometry is used to explain four different types of local reinforcements.

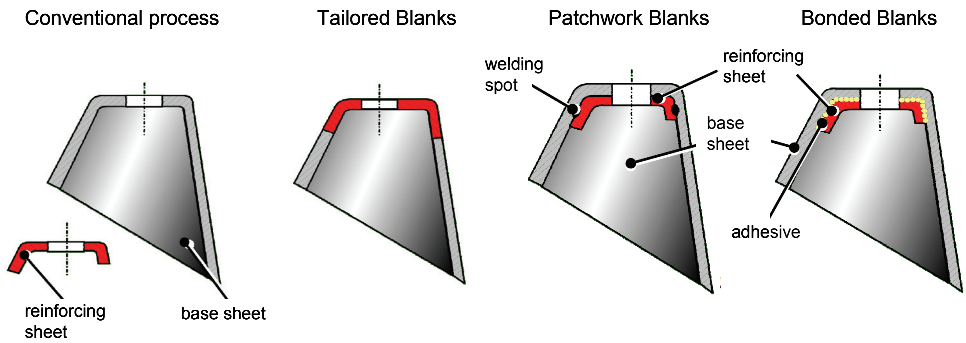


Figure 1 - Different types of locally reinforced sheet metal parts (strut support) [1]

The conventionally used process needs two separately formed sheet-metal parts which are joined in a following additional operation. Disadvantages of this procedure can be considered in the need of two separate forming operations with particular forming tools, high requirements concerning the precision of the two forming operations in order to avoid problems caused by non-matching parts and the additional challenges of handling an extra joining process step [1, 2].
Another method of processing locally reinforced structures is using the Tailored Blanks Technology. The area to be reinforced is being cut away in the plane blank before the forming process. The hole or indentation being incurred by this is filled by welding in sheet material of a different grade, a different thickness or even a combination of both of these. Afterwards the Tailored Blank is formed in one single forming operation [4, 5].

Patchwork Blanks are made of a reinforcing sheet welded on a base sheet or when using adhesive bonding, a curing process before forming is applied. This generates a very strong connection between the two sheets, co-occurring with a very limited level of relative movement between the two sheets. Another challenge is the demand on high precision in positioning and process handling caused by the different sheet thicknesses [2].

2.1. Applications for locally reinforced parts

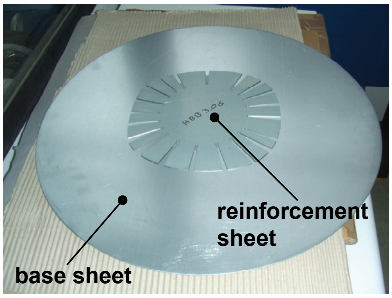
Many applications for locally reinforced parts can be found against the background of lightweight construction in vehicle and aircraft industry. The need to reduce weight of the parts to be integrated in the following generation of vehicles forces the constructing and designing engineers to optimize the used parts in their weight and their offered function. If it is possible to implement a further function into a part, this new feature could replace a part taking that task so far, whereby a reduction of weight can be achieved. Another idea is to generate parts with a specific sheet thickness in different areas. If the load to be beard can be localized within a part or if the load is carried into the part in a certain area, the strengthening of this area might reach the goals of durability in the same way than strengthening the whole part.

2.2. Steel sheet materials and Adhesives

As geometry of the part to be produced, a strut-support was selected. The geometry was optimized in CAD with the help of numerical simulation, in order to enable the concentration on the investigations of the locally reinforced area and to avoid unwanted effects caused by the geometry during forming process (wrinkling, cracking).
The characteristics of the investigated sheet metals and adhesives are specified in *Fig. 2*.

Sheet metal (lasercut)

base sheet (ø 600 mm)	reinforcement sheet
H340 LAD, s = 1.50 mm	H340 LAD, s = 1.50 mm
H220 YD, s = 1.15 mm	TRIP 800, s = 1.25 mm



Adhesives

adhesive	chemical basis	delivery form	temperatures	
			coating	activation
HCM 555 (Collano)	reactive polyurethane	powder	80°C (short)	> 140°C
Vestamelt X1333 (EVONIK)	reactive co-polyamide, melting adhesive	powder	150°C	> 165°C
Duplocoll TM-10850 (Lohmann)	melting adhesive (IPDI)	film	90°C (short)	> 150°C

Figure 2 - Sheet metal materials and adhesives

The two different base sheet metal materials H340 LAD with 1.5 mm sheet thickness and H220 YD with 1.15 mm sheet thickness (both with a zinc-coated surface) are combined with the H340 LAD and a TRIP 800 of 1.25 mm thickness. The blank cut was realised by laser-cutting. The geometry of the used reinforcing sheets was optimised with the help of numerical simulation. This concerns the number and arrangement of the support notches. An improvement was achieved by raising the number of notches as well as increasing their angle. Thereby, the remaining expanse of the ribs in the reinforcing sheets was reduced, which decreases their resistance against getting formed by the base sheet.

Adhesives capable for Bonded Blanks have to fulfil the basic condition of a very high viscosity in the deep drawing process because the polymer material must not squeeze out of the joint under high mechanical pressure. Adhesives with a hotmelt characteristic fit into the requirements because of staying as solidified plastic material at standard temperature conditions and when blended with reactive components, adhesive bonding in two steps is possible simple controlled by temperature [3]. The chemical basis of the different reactive hotmelt blends along with the delivery-form and the temperatures for coating and activation are shown in the table within *Fig. 2*..

The process chain of bonding and forming is built in the following way:

The base sheets are pre-coated with the adhesive, the joining process of the plane sheets can be established in a heated press for melting the thermoplastic hotmelt in the first bonding step. This is followed by the hydromechanical forming of the part, before the bonding is being activated by elevation up to activation temperature during the drying step in cataphoretic coating. The parts' operating temperature range must be located below the fixation and curing temperatures, which can be assumed for a vehicle-strut housing during normal operation mode (*Fig. 3*).

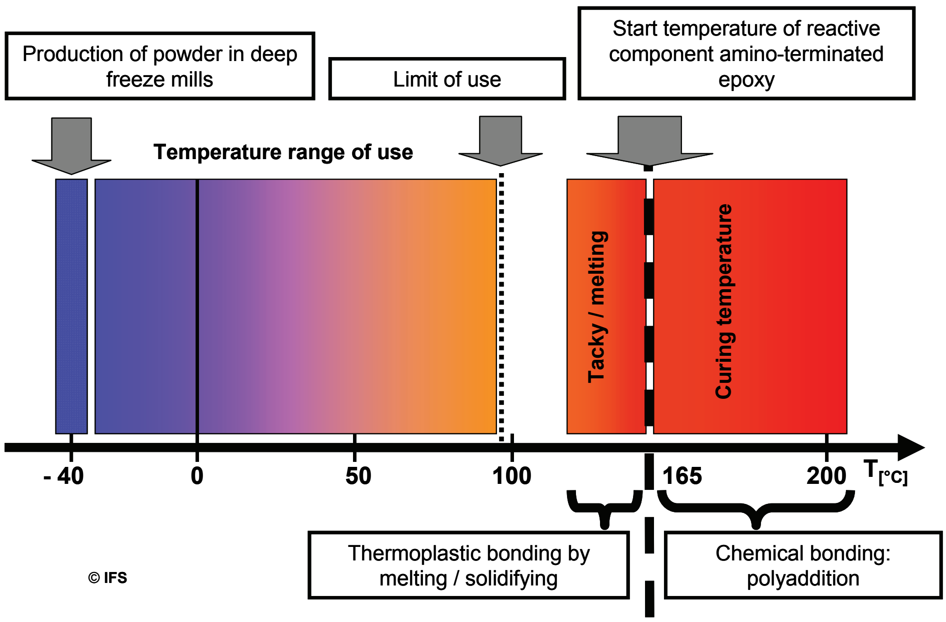


Figure 3 - Adhesives & temperatures (powders and foils)

3. HYDROMECHANIC SHEET METAL FORMING PROCESSES

The hydromechanical deep drawing process is classified as a deep drawing process using a working medium [6]. One possible process variant is the hydromechanical deep drawing with punch. Further variants are hydromechanic deep drawing with die or internal high pressure forming. Successful experience from preliminary research projects induced to use the variant with punch in this case, thus the more precise description of the other processes is expendable. The functional principle of the process with punch is composed of the followed described three steps (*Fig. 4*):

> In the first step the blank is positioned on the lower tool half which contains the pressure tank filled with working medium.
>
> As second step the blank holder closes and fixes the blank against the gasket to ensure a closed volume in the lower tool half is provided for the following forming step.
>
> In the third step, the punch drives down and forms the part against the raising medium pressure. A valve allows the regulation of the generated pressure.

As a variant of this procedure, the active hydromechanical deep drawing differs in step 2, by raising the pressure after the blank holder has closed to achieve an active pre-forming of the blank in the opposite direction of the following forming operation. This generates a pre-stretch forming and enables to stabilize sheet-metal parts with a low drawing depth [4].

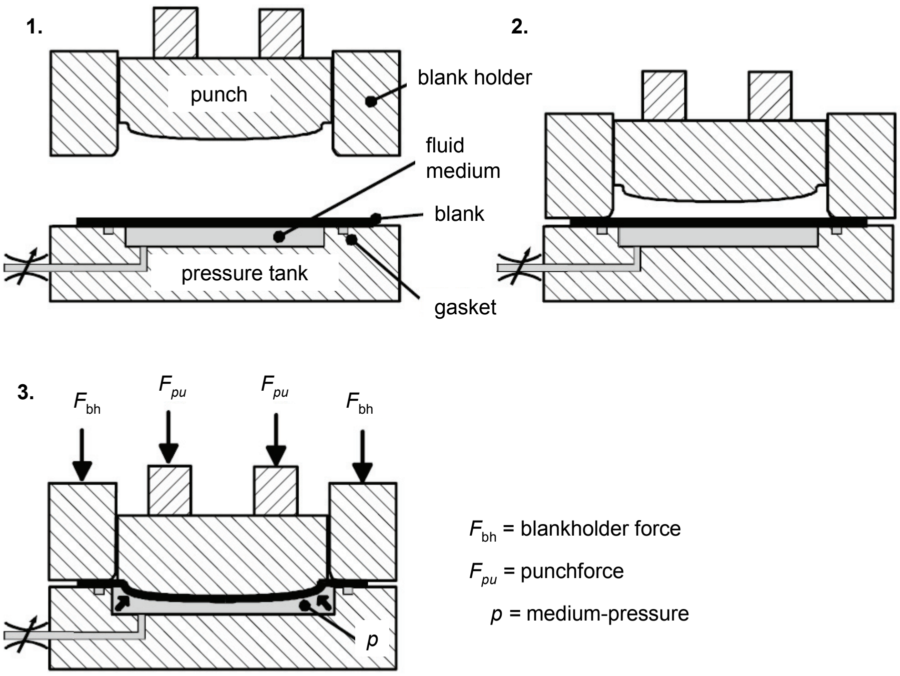


Figure 4 – Hydro-mechanic deep drawing with punch [3]

Three important characteristics of the hydromechanical deep drawing process are:

- low tool-costs through simple-die geometry,
- reduction of preparation time for adjustment procedures and
- forming of different materials and different sheet-thicknesses with only one tool. [1,4]

Another substantial feature can be seen in the process-specific state of stress occurring during forming. In comparison to conventional deep drawing, this state of stress enables to reduce the failure by wrinkling because of free forming zones (second wrinkling). The drawing especially of conical parts is facilitated thereby. The specific state of stress originates in the medium pressure impinging in a perpendicular direction to the parts surface at any time. *Fig. 5* shows the directed pressure in the area of contact to the parts' surface.

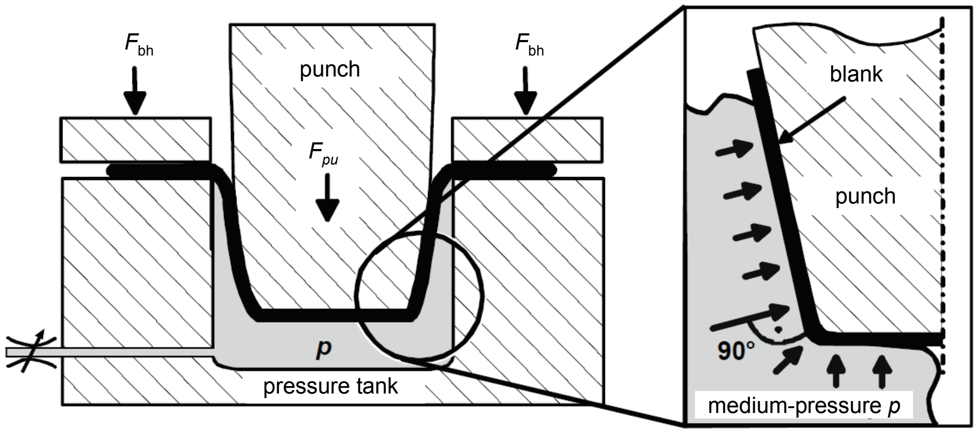


Figure 5 - Directed pressure on parts' surface during forming [3]

Because of the directed pressure, the amount of force which is transferable from the flange area through the architrave area into the bottom area rises.
This causes further special characteristics:

- higher drawing ratios in the first step,
- more constant sheet thickness,
- higher accuracy,
- high surface quality and
- more homogenious state of internal stress.

4. EXPERIMENTAL SETUP FOR HYDROMECHANIC DEEP DRAWING

The used tool for hydromechanical deep drawing of the reinforced sheets is mounted in a hydraulic deep drawing press of 1,250 tons pressing force.
Technical parameters of the used Schirmer and Plate Press:

max. pressing force:	12,500 kN	way of pestle:	500 mm
max. working pressure:	315 bar	work surface:	1,250 mm x 1,250 mm
max. pressing velocity:	28 mm/s		

A special feature of the tool is represented by the elastic-binder system. Eight plunger cylinders arranged around the punch enable the local control of different binder-areas by certain adjusted local binder forces. The plunger cylinders are getting compressed during forming-process by the upper tool-half driving downwards. Each cylinder is connected to a valve controlling the amount of hydraulic fluid to be pressed out and thereby setting the adjusted pressure. This technique allows leading in certain forces into the flange of the sheet in different areas, which helps to achieve a better forming result with a reduced appearance of wrinkles and cracks. The tool-design and the mounted tool in the press are shown in *Fig.6.*

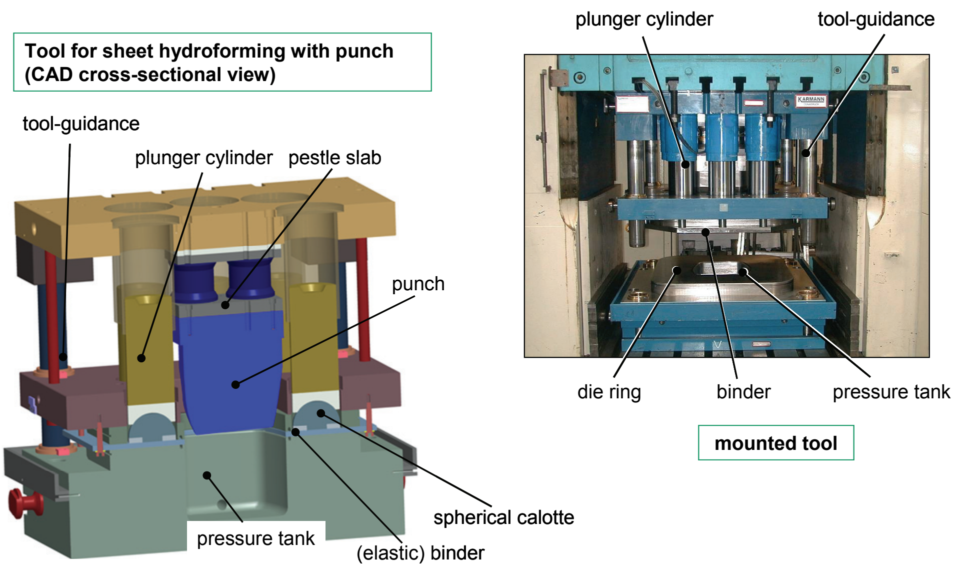


Figure 6 - Tool design and assembly with elastic binder

The forming-pressure inside the pressure tank is generated by the movement of the punch. The extrusion of the working fluid by the punch driving down the tank is regulated by a valve adjusting the preset pressure. Since the binder plunger and the tank-valve are sharing one medium-circuit, the two movements are influencing each other.
The best results according formability were achieved with the pressure in the tank set at a specific level: The idea is to keep the pressure on a certain level supporting the movement of the blank-material around the drawing edge. If the pressure level is set too high, the sheet bulges in the opposite direction of forming. If it is set too low, the sheet follows the regular way and is subject

to the friction conditions like in regular deep drawing. An increasing appearance of cracks initiated by the thicker reinforcing sheet notching the thinner base sheet can generally be noticed in these types of combinations. The problem increases with growing sheet thickness of the reinforcing sheet as well as along with using steel grades of higher strength.
Another challenge in this production technology is caused by some adhesives reacting to components of the used hydraulic pressure medium. Even though the reinforcing blank is located between punch and base sheet, the contact of the adhesive to these kinds of fluids can not be completely avoided during forming process. This is caused by the punch getting in contact with the fluid in case of cracking, but also getting in contact with the used lubricants of the forming machine and tool components in action. Certain ingredients in the oil may cause a delamination of the bonded reinforcing parts in local areas or on the entire surface. Even though in the beginning only small areas are affected by this, the capillarity between the two sheets causes a spreading of this condition into further areas.

5. FORMING ANALYSIS

In order to analyse the forming process, the analysing system AutoGrid of the Vialux company was used. This technique uses a regular square-pattern which is electrochemically etched on the blanks' surface before forming. After forming, a system of four cameras detects the formed grid of square and recalculates values like the degree of forming, the sheet thickness and so on. Each distorted squares has to be detected by at least three of the cameras, whereby the recording and editing of the measurements have to be accomplished accurately. The degree of forming along with the state of stress can be illustrated in a forming diagram as described in *Fig. 7*.

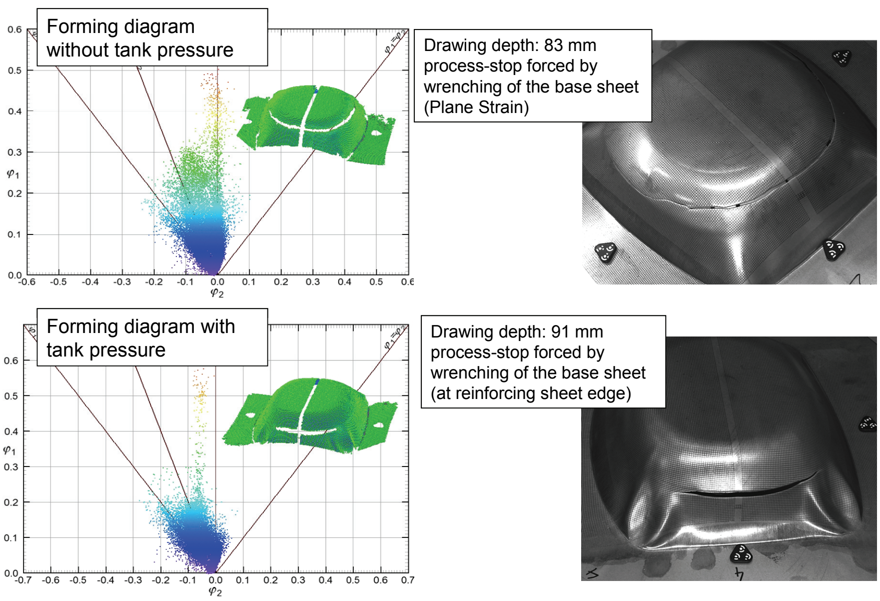


Figure 7 - Forming diagrams of locally reinforced parts, hydromechanically deep drawn with respectively without applied tank pressure

It shows the comparison of the forming analysis of a part formed with regular deep drawing process to one formed by hydromechanical deep drawing. The locally reinforced part is a combination of a 1.5 mm H340 LAD base sheet joined with a 1.5 mm H340 LAD reinforcement sheet by a reactive co-polyamide melting adhesive (X1333). Regular deep drawing was achieved by forming without working medium in the tank and thereby without tank pressure.

The main difference between the two parts is the localization of the appeared cracks. In regular deep drawing process, the crack appears slightly earlier and in the bottom area of the part while the crack in hydromechanically deep drawn part appears in the edge area of the reinforcement sheet. Another difference is the state of stress calculated by the system. The part from regular deep drawing shows a lower degree of stretch forming than the part from hydromechanical deep drawing. Since this is the first phase in deep-drawing process, the regular deep drawn part loses that reserve of formability in the second phase, because it already generated more forming out of the other areas at that time. The counter pressure increases the punch force transferring area and thereby the allowable radial stresses [6]. Furthermore the material of the part formed with hydromechanical deep drawing seems to slide in a more gentle way around the edge of the die-ring, which shows in less intensive scratching-marks to be found on its surface and a less sharp shaped edge in this specific area.

6. CONCLUSION

The proof of concept was achieved by successfully hydromechanical forming of different sheet metal materials in combination with different adhesives. Principally a combination of two sheets of similar thickness together with a certain layer of adhesive obtains the best forming results. The combination of thick reinforcements with thin base sheets causes a cracking in an earlier stage of forming compared to the combination of similar sheet thicknesses.

Furthermore, the results of the forming analysis show that the hydromechanical deep-drawing process has a noticeable effect on the forming. This shows in the achieved extension in process limitations in terms of parts' formability. Furthermore, the optimization of the used reinforcing sheet geometry with the help of numerical simulation improved the formability. This exposes that the technology of hydromechanically deep drawing of bonded blanks is suitable to contribute its share to the challenges caused by the demand on lightweight construction in production technologies.

7. OUTLOOK

An issue of following scientific work on hydro-Bonded Blanks can be seen in the combination of the forming process with a heat-treatment. The used adhesives improve their skills in enabling a sliding of the two sheets during forming at a temperature level of 80°C up to 120°C significantly. Since the used tool system is not able to handle these temperatures because of operating range of the hydraulic device, investigations on that influence can only be realised with a new tool system.

The improvement in the formulation of the adhesives and their handling should be investigated in more depth as well as the optimal preparation of the blank-surfaces concerning the following bonding-process.

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LOKALNO OJAČANI LIMOVI DOBIJENI "HYDRO BONDED BLANKS" TEHNOLOGIJOM

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REZIME

Lokalno ojačani delova od lima mogu se uspešno koristi za smanjenje težina konstrukcija odnosno izradu tkz. lakih nosećih konstrukcija. Takođe, primena ovih limova omogućava prilagođavanje (optimizaciju) geometrije delova ili mašina aktivnom opterećenju. Jedna od mogućnosti za proizvodnju lokalno ojačanih delova je postupak zasnovan na Bonded Blanks tehnologiji, gde se prvo osnovni lim lokalno spaja sa ojačanim limom i to u dve faze, a zatim se ceo spoj zajedno deformiše (oblikuje) u samo jednoj operaciji dubokog izvlačenja. Konačno očvršćavanje spoja odvija se pod dejstvom toplote za vreme sušenja u kataforetičnom sloju.

Ovaj rad se bavi istraživanjem efekata hidromehaničkog dubokog izvlačenja limova sa lokalnim ojačanjem, dobijenih Bonded Blanks tehnologijom. Pri tom testirani su različiti materijali limova i vezivna sredstva.

Ključne reči: *Bonded blanks, hidromehaničko duboko izvlačenje*