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Investigation Of Tailored Blank Production By The Process Class Sheet-Bulk Metal Forming

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Abstract. Nowadays efforts are made to improve sheet metal manufacturing processes and forming capability. Functional sheet metal components, for example toothed synchronizer rings, show closely-tolerated complex geometric features, especially in the automotive industry. Unfortunately sheet metal forming operations do not offer the possibility for complex shapes as do for example cutting technologies [1]. To avoid this restriction, the usage of semi-finished products with a material pre-distribution in the blank is investigated. So-called tailored blanks are usually made of different materials or sheet thicknesses. A common way of joining diverse blanks is welding [2]. In most cases the joining has a significant influence on the consecutively forming process due to varying local mechanical properties [3]. Hence the manufacturing of tailored blanks with a defined sheet thickness characteristic by the process class “sheet-bulk metal forming” is investigated. Subsequent the tailored blanks are provided for forming operations such as deep-drawing and the direct forming of complex functional shape elements. Aim of the project is the manufacturing of circular blanks with a sheet thickening in the exterior area by an upsetting operation. At the beginning, FE-based studies and physical experiments using blanks of DC04 are carried out, to create a fundamental knowledge base of the forming process. A comparatively large contact area between blank and forming tool, a three-dimensional material flow and the low sheet thickness cause high process forces. Building up a multi-stage upsetting process with different sequenced tool geometries is one approach to meet this challenge. The material flow out of the sheet center is realized step-by-step to lower the actual contact area and sequential the appearing forces.

Keywords: Sheet-Bulk Metal Forming, FE-Simulation, Tailored Blanks.

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INTRODUCTION

The process “sheet-bulk metal forming” is investigated to produce functional components with complex geometric features out of a sheet metal by using bulk forming processes like upsetting or extrusion. The considerable variation of sheet thickness and appearance of high local strain discrepancies are characteristics, which represent a localized forming zone in the blank. Examples of manufactured components are seat slide adjusters and synchronizer rings, which are used for automotive applications, formerly made of brass and manufactured by cutting or forging. To fulfill the requirements of high mechanical load capacities, tight tolerances and low production costs, steel synchronizer rings produced by forming are of great interest [2]. The direct forming process of thin-walled parts with functional

components requires a material pre-distribution in the initial blank in order to assure sufficient mould filling and enhance successive forming operations.

Tailored Blanks

Over time, endeavors were done to improve sheet metal workability and to optimize production processes. Thus, different types of tailored blanks manufactured by welding and plastic deformation have been investigated, in order to realize sheets with varying local mechanical properties, different quality of materials and sheet metal thicknesses. Compared to conventional semi-finished products, tailored blanks provide a weight reduction potential of 20-34 % [1]. A common way of joining different blanks is welding [4]. In most cases the joining has great influence on successive forming operations due to varying local mechanical properties, which makes novel manufacturing techniques desirable [3]. Moreover tailored blanks produced by forming show improved mechanical properties such as high strength and a homogenous grain structure, but the reachable geometric design is restricted. Formed tailored blanks are typically manufactured by rolling. Rolling processes with a varying roll gap allow the production of blanks with adjustable sheet thickness in rolling direction. Novel processes enable a material flow in the direction of the strip width by using narrow rolls. Accordingly the manufacturing of blanks with a thickness profile perpendicular to the rolling direction is possible [5, 6].

Aim of this work is the manufacturing of rotationally symmetric tailored blanks with defined sheet thickness characteristics respectively mechanical properties by the process class “sheet-bulk metal forming”.

TAILORED BLANKS MANUFACTURED BY SHEET-BULK METAL FORMING

Initial Situation

Vision of the research project “sheet-bulk metal forming” (DFG SFB/TR 73) is the fundamental investigation on a new manufacturing technology, that will unite the advantages of sheet and bulk metal forming processes in term of flexibility and possibilities. The technology eliminates the limitations each of these two groups of forming processes. In the focus of investigations in this article is the development of an upsetting process to produce tailored blanks with a defined varying sheet thickness.

The manufacturing of tailored blanks by sheet-bulk metal forming is carried out at room temperature, providing complex geometries and improved mechanical properties in further production steps. Whereas sheet metal forming usually is characterized by biaxial stress states, the investigated sheet-bulk metal forming process realizes a three-dimensional material flow due to the desired spatial thickness distribution in the blank [7]. Material is transferred to target regions in order to prepare the semi-finished products for further process steps like deep drawing, extrusion or upsetting of complex

shapes elements. The initial circular blank, made out of the steel DC04, has a sheet thickness $t_0 = 2$ mm and a diameter $d_0 = 100$ mm. An adapted material distribution in the blank is realized by using axially symmetric punch tools. The upsetting force provides radial material flow and thus sheet thickening in the exterior blank area. To generate a fundamental knowledge base of process parameter influence with regard to material flow and forming force, upsetting operations using the FE-software Simufact.forming 9.0 are simulated. Afterwards physical experiments are carried out to produce components and validate the results of FE-analysis. Some aspects of the process, like the big contact area and the investigated sheet metal components, are comparable to coining. But high plastic strains, mainly in following forming steps, and the defined material flow are different. Furthermore the shape element size within the desired parts is, in contrast to coining, in the same magnitude as the sheet thickness.

Experimental Setup

The experimental setup of the forming tool in Figure 1 consists of a punch and a counterpunch, which is arranged within the die and can be activated hydraulically to eject the formed blanks. A reinforced die prevents an increase of the sheet diameter to build up the requested material accumulations. A pressure sensor, which measures the hydraulic upsetting force indirectly, and the extensometer allow process control and comparison to FE-simulation.

FIGURE 1. Experimental setup of the upsetting tool.

Three diverse punches (see Figure 2) with different shoulder diameters ($d_s = 60$ mm, 70 mm and 80 mm) are designed to accomplish a blank thinning in the center area and create circular material accumulation at the exterior region. Effecting an enhanced material flow, a bevel of $\alpha = 0.5^\circ$ is integrated at the punch bottom. Due to low sheet thickness, spatial material flow and comparatively large contact area between tool and blank, the forming process brings up a lot of challenges to deal with. High upsetting forces have to be accounted designing the forming tool and developing process strategies. One approach to meet this challenge is building up a multistep

forming process in order to accomplish a step-by-step flow of material caused by three sequential tools with different shoulder diameters d_s , starting with the smallest and going to bigger ones. This strategy enables a reduced contact area, considerable lower process forces and accordingly lower tool load. The successive punches with increasing shoulder diameters transport material to the exterior area of the blanks at each step. Thus the desired mould filling is achievable without plastification of the entire blank, which would be inevitable using a single-stage forming operation.

FIGURE 2. Punch tool geometry with different shoulder diameters of $d_s = 60$ mm, 70 mm and 80 mm.

FE-Simulation and Experimental Results

At the beginning investigations with the first punch ($d_s = 60$ mm) are carried out. Due to appearing high contact stresses the Tresca friction law with a friction factor of $m = 0.15$ is used as contact condition in the FE-software Simufact.forming 9.0 [8]. As a result of the low sheet thickness, even little elastic tool deformations can influence the results observable. Thence the elastically behavior of each tool component has to be considered designing the FE-model. The circular blank material was assumed to be elasto-plastic by using a hexahedron mesh. Figure 3 shows the tailored blank with an increased sheet thickness $t > t_0$ in the exterior area applying a maximum upsetting force of $F_{\max} = 5.000$ kN.

FIGURE 3. Tailored blank forming result of (a) FE-simulation and (b) physical experiment.

In Figure 3a) the largest plastic strains can be seen at the transition area of the formed blank. For the manufacturing of sheet metal components with integrated shape elements, like the toothing of synchronizer rings, functional components have to be formed in further production steps such as upsetting or extrusion. Therefore a comparatively low work hardening in the sheet thickening region ($t > t_0$) is eligible for subsequent processing to gain components with functional elements in the exterior sheet area.

FIGURE 4. (a) Axial sheet thickness and (b) process force / punch stroke of the tailored blank upsetting operation.

The axial sheet thickness characteristics and the process force / punch stroke of the tailored blank forming operation can be seen in Figure 4. The material flow in the sheet center results in a decreased thickness of approximately $t = 1.7\text{--}1.8$ mm. Accordingly the radial material flow causes a desired sheet thickening in the exterior area. The rising local strain hardening, mainly at the sheet thickness transition (see Figure 3), with increasing upsetting force, constrains material flow in the blank and thus mould filling. Furthermore the degradation of tribological conditions and high mechanical loads lead to large friction shear stresses. This effect can be explained by the lubricant film flow out of the forming zone, as the punch shows a lubricant free surface after the upsetting experiment. The tool movement and accordingly plastic forming process aborts, which declares the non uniform blank thickness in the outer area with a maximum of almost $t = 2.3$ mm. Moreover the effect of the elastic counterpunch deformation can be seen in Figure 4 a). A comparatively large residual sheet thickness in the blank center ($t = 1.8$ mm, $x = 0$ mm) in contrast to the exterior transition region ($t = 1.7$ mm, $x = \pm 30$ mm) can be explained by the beveled punch shoulder geometry. Because of a major elastic tool deformation in the counterpunch central area, the fraction of sheet thinning compared to the complete punch stroke decreases and a larger sheet thickness remains. The process force in figure 4 b) exhibits a nearly linear characteristic with a rapid increasing at the beginning and a maximum of $F_{\max} = 5.000$ kN. The experimental results and FE-simulation show a similar behavior with very low discrepancy. By modeling all tool components as elastic bodies, the calculated punch stroke is in accordance with the forming experiment.

SUMMARY AND OUTLOOK

The investigations have shown that sheet-bulk metal forming is applicable for the production of rotationally symmetric tailored blanks. Using upsetting tools, a pre-distribution of material can be achieved in the exterior area of a circular sheet blank. Thereby tailored blanks are well prepared for further forming operations like deep-drawing or extrusion to manufacture components similar to synchronizer rings. Due to the high process forces, the elastic tool deformation and friction conditions are issues to be considered in further investigations. The elastic tool deformation reaches a maximum in the counterpunch centre. Therefore the surface may have a convex shape to reach a planar area under load. This approach is already known from strip rolling technology, where tools are bossed to compensate elastic deformation. The tribological condition respectively friction shear stress between tool and blank has to be decreased enhancing the process. A sufficient lubricant distribution effects lower upsetting forces and provides high quality components.

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