Influence of alternating bending on springback behavior of parts in deep drawing process with macro-structured tools

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Abstract. In today's industry, waste prevention and an efficient use of resources are becoming more important due to economic and environmental requirements. Especially in forming processes such as deep drawing, a reduced use of lubricants is highly promising for saving resources and reducing production costs. Deep drawing with macro-structured tools is a novel approach to reduce the amount of friction forces and realize a lubricant free process. The induced alternating bending in sheet metal during the deep drawing process with macro-structured tools leads to an increase of its geometrical moment of inertia and consequently stabilizes the sheet against wrinkling. The induced alternating bending increases the back force in the sheet metal during the process and as a result affects the springback behaviour of the formed part. Furthermore, the resulted cyclic loading in flange area can leads to a kinematic hardening of some material. Within the scope of this paper, the influence of alternating bending on springback behaviour of parts in deep drawing process with macro-structured tools is studied. For this purpose, numerical simulations as well as experimental tests to form a U-channel with macro-structured tools are carried out.

Keywords: Springback, Deep drawing, Hardening

1 Introduction

Lubricant is essential in the conventional metal forming to reduce the friction between tool and workpiece and forming energy, increase the forming limit, and to prolong the tool life by prevention of galling and seizure. High amount of wasted lubricants has become a great nuisance of environmental issues [1]. Therefore, lubricant free deep drawing is attractive toward zero emission of lubricants in sheet metal forming [2]. As one of the most promising methods, use of macro-structured deep drawing tools [3] is highlighted because of its performance to reduce the friction forces and simplicity in application. In [4] it is shown that in order to decrease the amount of friction force for a given friction coefficient, the integral of the contact pressure over the contact area can be reduced by means of macro-structured tools. In this way, the contact area between the workpiece and tools will be reduced to a small number of lines.

By reducing the contact area in flange area, the risk of wrinkling in the unsupported sheet metal parts will be increased, because the usually utilized blankholder force is not applicable. By increasing the geometrical moment of inertia of the sheet, this effect can be avoided. In this new developed process, it is achieved by immersing the macro-structured blankholder slightly into the drawing die and inducing an alternating bending mechanism in flange area. The induced alternating bending leads to a cyclic loading in the sheet metal, which can cause a kinematic hardening for some materials. Figure 1 compares the conventional and lubricant free deep drawing process with macro-structured tools.

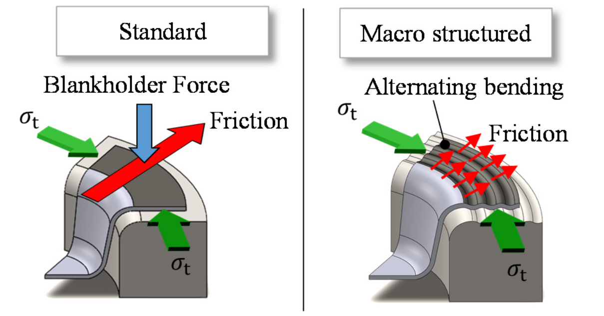

Fig. 1. Comparison between standard and macro-structured deep drawing process.

Depending on the geometry of macro-structures, wave length λ and immersion depth δ (as shown in Figure 2) are two parameters in macro-structured deep drawing process which determine the bending mechanism and can be used as setting parameters to ensure a stable process.

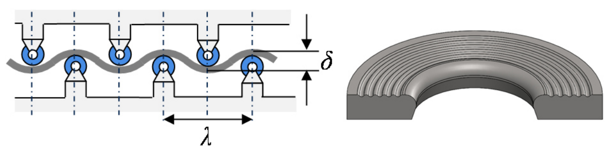

Fig. 2. Bending mechanisms by deep drawing with macro-structured tools.

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By increasing the immersion depth or decreasing the wavelength the bending curvature will be increased. Therefore, the restraining force in flange area which can be used to compensate the springback will be increased. From the other side, a kinematic hardening as well as Bauschinger effect due to cyclic loading can tack place. This should be also considered as a secondary effect of process on springback behaviour of products. Figure 3 illustrates schematically the difference between isotropic and kinematic hardening behaviour of materials.
Generally, the Bauschinger effect is very important parameter in sheet metal forming because it has been associated to the influencing parameters on final part geometry such as springback. This phenomenon, which refers to the elastic distortion of a part when forming loads are removed, is a major issue in sheet metal forming and its reduction is of importance [5].

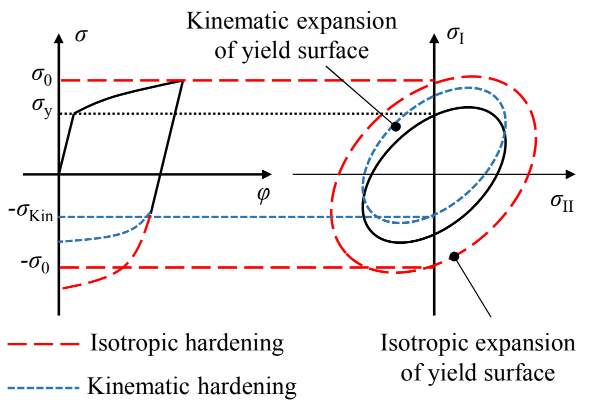

Fig. 3. Comparison between pure isotropic and kinematic hardening.

In order to control the accuracy of parts made by deep drawing with macro-structured tools, it is necessary to have an appropriate investigation about the phenomena that occurs during cyclic loading, such as the Bauschinger effect, the isotropic and kinematic hardening. Within the scope of this paper, the influence of restraining force caused by alternating bending and also the Bauschinger effect as a result of cyclic loading on springback behaviour of parts in lubricant free deep drawing process with macro-structured tools is studied.

2 Methods for reduction of springback in sheet metal forming operations

In sheet metal forming, the shape of the blank obtained at the end of the forming step closely conforms to the geometry of tools. However, as soon as the loads are removed, elastically-driven change in the blank shape and so called springback takes place. In the automotive industry, engineering guidelines and finite element software are used in the design process for new sheet metal parts. Very often during the design process the level of springback is numerically predicted. Based on this prediction, the tools' geometry and process parameters are modified to obtain the desired product shape [6]. However, the current accuracy of springback prediction is not sufficient [7]. Therefore, there is a need to start an extensive experimental trial and error process to determine the necessary tools' geometry and other variables, which will enable production of the required product shape. As a result, the product cost and the time from design to production are increased considerably. There are several commonly used methods to reduce the springback in conventional deep drawing process:

- Blankholder force control: The method is based on increasing the friction force during forming, and thus increasing the tension in the sheet materials flange [8]. However, this can increase the risk of bottom crack in the specimen due to the high friction force.
- Through thickness deformation: In this method the springback is decreased by deforming locally certain corners of the parts [9]. This method can also leads to a locally overloading of the specimen and as a result causes surface defects or even bottom crack.
- Forming in multiple steps: In this method a product is produced by means of several tool sets or by means of one tool set with some additional mechanisms. This way increases the process complexity and results in a time-consuming process.

As it mentioned above, conventional methods for reduction of springback are either difficult to apply or even cause other geometrical problems in the part. However, lubricant free deep drawing process with macro-structured tools can besides the reduction of friction also provide further advantage regarding springback reduction by increasing the restraining force through alternating bending. In order to determine the influence of alternating bending on springback reduction of products, some numerical and experimental investigation are carried out in this study.

3 Objective and approach

In order to determine the effect of restraining force as a result of induced alternating bending on springback behaviour of deep drawn parts with macro-structured tools, draw bending of a U-Chanel is considered. This method is attractive because the level of springback due to the 90° bending is relative large and it can easily be measured. Sensitivity of springback to basic parameters, such as tool radius, sheet thickness, geometric parameters of the tools, mechanical properties of sheet material and friction parameters is usually studied by means of this technique [10]. Furthermore, the U-Channel parts are common elements in industrial sheet metal forming. It appears in many auto-body cover panels like side members and beams.

To get an information about the effect of material on springback in deep drawing with macro-structured tools, three different types of industry-relevant materials like cold rolled DC04 (1.0338) as a low-carbon steel, DP600 (1.0936) as a multiphase high-strength steel and also the aluminium alloy AlMg4.5Mn0.4 (EN AW-5182) are subjected for numerical and experimental tests. In order to study about the effect of restraining force caused by alternating bending on springback behaviour of workpiece, the process without alternating bending (δ =

0.0 mm) is compared to the process with alternating bending (δ = 0.2 mm). Furthermore, in order to examine the effect of kinematic hardening on springback of the workpiece during the process, the materials are considered with pure isotropic, pure kinematic and also combined hardening behaviour in the numerical simulation. The Bauschinger coefficient of each material for the combined hardening rule are taken from literature [11], see Table 1. The process is simulated with a 2D FEM-Model (Marc Mentat v. 2017) with plane strain solid elements (7 elements across the sheet thickness of 1 mm) and a constant friction coefficient of μ = 0.1 based on Coulomb friction model.

Table 1. Bauschinger coefficient of three testing materials [11].

Material	Bauschinger coefficient
DC04	0.70
Al 5182	0.75
DP600	0.40

4 Experimental setup

The springback behaviour of the specimens is investigated by means of draw bending of a U-Channel with macro-structured tool from tool steel 1.2162 (21MnCr5) and die edge radius of 10 mm. The contact area of the tool is polished to reach a roughness of R_a = 0.3 µm and R_z = 0.5 µm. Here a rectangular punch (82 mm × 82 mm) with an edge radius of 10 mm is used. The drawing gap is then 1.75 mm from each side of tool. The gap between blankholder and drawing die can be adjusted by using the spacer strips on the unstructured area of the tools. Figure 4 shows an overview of macro-structured tool with a constant wave length of λ = 9 mm.

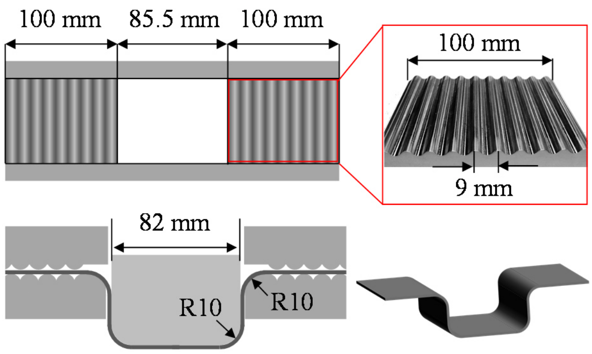

Fig. 4. Geometry of macro-structured draw-bending tool.

All tests are carried out with hydraulic press machine BUP 600 from Zwick / Roell at room temperature with a constant drawing velocity of 5 mm/s and in dry condition. Workpiece strips are cut from DC04, DP600 steel and Al 5182 aluminium alloy with 1 mm thickness, 60 mm width and 280 mm length. Each strip is cold-rolled, cleaned using a citrus based cleaner and finally treated with acetone to remove all traces of pre-lubricants and to assure a comparable test condition. All tests are repeated five times in order to get an information about the statistical repeatability of the results.

5 Results and discussion

In order to simulate the draw bending process with FE-method, the flow curve of all three specimens is determined experimentally through tensile test. The curves are extrapolated up to the equivalent plastic strain of 1.0 regarding the isotropic hardening model of voce based on following relation [12]:

$$\sigma_y = \sigma_\infty - (\sigma_\infty - \sigma_{y0}) \cdot e^{-m\varepsilon} \qquad (1)$$

where σ_∞ is the asymptotic value for saturation strength (ultimate strength), σ_{y0} is the initial value of isotropic hardening, m and ε are the characteristic strain constant and equivalent plastic strain respectively. The corresponding parameters for the voce model are listed in Table 2.

Table 2. Parameters for the Voce model for three testing materials.

Material	σ_∞	σ_{y0}	m
DC04	405	175	9
Al 5182	375	150	9.5
DP600	750	350	22

The resulting flow curves for all three materials are shown in Figure 5.

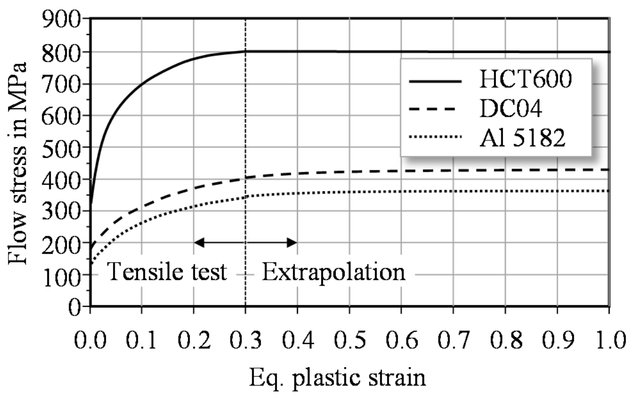

Fig. 5. Flow curve of three testing materials.

The springback behaviour of U-Channels can be characterized regarding the final part geometry with three parameters: the angle between the bottom and the wall θ_1, the angle between the wall and the flange θ_2 and the radius of curvature of the sidewall ρ. As θ_1 and θ_2 increases and ρ decrease, springback increases. Fig. 6 shows the springback geometry of a U-Channel cross section. In this study the effect of process parameters on deflection angel θ_1 is studied.

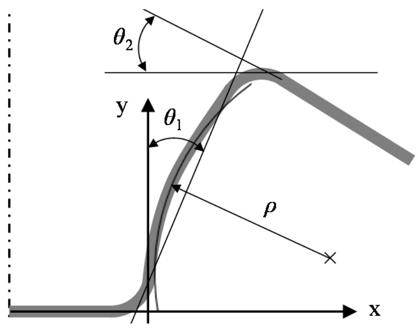

Fig. 6. Schematic overview for springback geometry of a U-Channel.

5.1 Investigation about the effect of back force caused by alternating bending on springback

In order to compare the materials regarding their springback behaviour, specimens from different materials are subjected to experimental test with macro-structured tools under immersion depth of δ = 0.0 and δ = 0.2 mm. As the Figure 7 shows, the springback of workpieces will be reduced through generating an alternating bending mechanism. This is due to the induced tensile force in flange area. The experimental results reveal that the elastic springback of aluminium alloy is higher than DC04 and DP600 because of its smaller value of Young's modulus. Furthermore, the elastic springback of DP600 is higher than DC04 because of its higher yield strength. Therefore, it can be concluded that springback is a severe problem in high-strength aluminium alloys as it is in high-strength steels because of the high strength-to-modulus ratio.
In order to investigate the effect of kinematic hardening as a result of alternating bending on the springback of workpieces numerical simulations are performed.

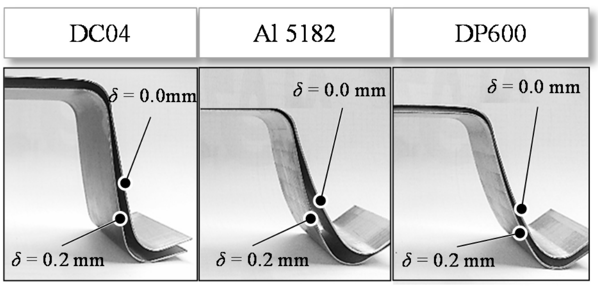

Fig. 7. Springback behaviour of workpieces with and without alternating bending.

5.2 Investigation about the effect of kinematic hardening on springback

The numerical results based on FEM-simulation for draw bending of U-Channel with macro-structured tools reveals the fact that the restraining force caused by alternating bending in flange area compensate the springback of workpiece regardless of hardening type. As the table 3 shows, the springback will be reduced by generating alternating bending for all hardening types in all testing materials. The results show that the alternating bending can reduce the springback effect of materials with pure isotropic hardening more than materials with pure kinematic hardening behaviour. Generally, when the pure kinematic hardening is used for numerical simulations, the springback amount is considerably underestimated, suggesting that the pure kinematic hardening is not adequate to predict the material response of the specimens [13].
Since springback is a function of yield strength, material softening during the alternating bending can slightly affect the amount of springback of materials with predominate kinematic hardening behaviour [14]. However, the experimental as well as numerical results show that considering these opposite effects, the restraining force has a major influence on the springback behaviour of materials.

Table 3. Springback angel of U-Channels under different hardening type.

Material	Numerical						Experiment	
	Pure isotropic		Pure kinematic		Combined		-	
	δ in mm		δ in mm		δ in mm		δ in mm	
	0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2
DC04	8.8°	4.1°	9.8	7.5°	9.2°	5.0°	9.7°	7.4°
Al 5182	14.2°	9.6°	15.6°	11.3°	14.5°	10.2°	17.8°	12.1°
DP600	14.8°	11.2°	18.0°	13.6°	16.9°	12.9°	18.4°	15.2°

6 Summary and conclusion

Today, more than 15% of the total cost of sheet-metal forming process is spent on lubricating liquids (buying the lubricants, lubrication process, cleaning the parts for following processes, waste disposal) [15]. Moreover, lubrication has a great impacts on the environment and the health of the workers. Thus, it is of importance to develop a process which permit a significant reduction of the amount of lubricating agents or even dry metal operation. Deep drawing with macro-structured tools is a new developed process which can reduce the friction force through minimization of contact area. The induced alternating bending can besides the stabilization of material against wrinkling leads to compensation of springback. A part of total punch force in deep drawing process with macro-structured tools is to bend and unbend of sheet metal between the tools structures. This leads to a tension in sheet metal in drawing direction which can compensate the springback behaviour of workpiece. Experimental results reveals that the springback can be reduced between 17 to 32% depending on the material by δ = 0.2 mm. The amount of springback reduction can be slightly affected through Bauschinger effect by materials with predominate kinematic hardening behaviour.

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