Prevent of Wrinkling and Rupturing Using a New Method Based on Punch Force in Hydro-Mechanical Deep Drawing Process

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Abstract: - An numerical investigation on the control of process parameters for the hydromechanical deep drawing with special attention to control of the blank holder force (BHF) is carried out. Sheet material St14 (Draw Quality Steel) of thickness 1 mm was used for this study. The effect of the counter pressure in the hydromechanical deep drawing process is investigated in combination with different constant levels of the BHF. An attempt to improve partial quality by control the blank holder force according to the punch force have been explored. For the fracture prediction in this paper the forming limit diagram (FLD) Will be used. The thickness distribution has been used for comparing between constant BHF and Variable BHF. The results showed that rupturing and wrinkling controlled by using variable blank holder force based on punch force.

Key-Words: hydromechanical deep drawing - Finite Element Method - Wrinkling - Variable Blank Holder Force - Closed loop Control - Strain Analysis

1 Introduction

During the deep drawing of axisymmetric cups, The value of the BHF is an important factor to eliminate wrinkling, and in the mean time, not to cause fracture. If the BHF is low, wrinkling may occur. On the other hand, if it is too high, fracture will occur. If a constant BHF is used, then the BHF should be kept within a certain operating range to obtain the desired depth.

Considering the fact that different modes of failure becomes important at different punch travels during the deformation, the BHF does not have to be kept constant throughout the deformation. Wrinkling at the beginning of the deformation due to large compressive stresses in the flange of the cup. However, as the deformation progresses radial stresses buildup in the wall of the cup and fracture may occur due to an excessive amount of stretching. Therefore, the BHF should be varied during the forming process instead of being kept constant.

There are several methods suggested in the literature to identify the variation of the BHF during the forming process. A large effort has been put into research covering variable BHF in the CDD process. Research is still on going and in focus at different places, see for instance [1–6]. In the following, a short review of the different suggested approaches is given and it is observed that there is a large difference between the proposed methods as well as between the suggested profiles for the BHF Traditionally, the BHF is applied as a constant value throughout the deep drawing process, or a fixed gap is used to prevent wrinkling. To better utilize the material or to make the drawing possible, other methods of applying and controlling the BHF may be necessary. Fig. 1 shows schematically a number of principal profiles for the BHF.

Figure 1: Overview of different methods of controlling the blank holder force.

Traditionally, the BHF is applied as a constant value throughout the deep drawing process, or a fixed gap is used to prevent wrinkling. The BHF can also be applied using a fluid [7]. To better utilize the material or to make the drawing possible, other methods of applying and controlling the BHF may be necessary. Fig. 1 shows schematically a number of principal profiles for the BHF.
The BHF profiles illustrated in fig. 1 are presented shortly in the following. An increasing BHF can be beneficial to prevent wrinkling near the end of the drawing [8] and also for improving shape fixability and to reduce spring back [8–13], which is of particular importance for aluminum alloys. A low BHF allows more draw-in of the material and this may cause wrinkling in the die shoulder area [14]. Especially for non axis-symmetric parts, the wrinkling tendency is high at the initial stage of the drawing and an initial high BHF is needed to suppress wrinkling, later the BHF is reduced to avoid tearing [15–16]. An increasing draw ratio compared to a constant BHF is possible using a decreasing BHF and an increase of the process window between wrinkling and fracture has been observed [17]. A BHF proportional to the punch force was proposed in [18–19] and shows less thinning than a constant BHF and reduced ear clipping. The punch force is also lower with this type of BHF control and the LDR is slightly higher [18].

There does not seem be to a general accepted profile for the BHF, even though much research have been done with the “fracture limit BHF method” proposed by Manabe et al. [20], where the BHF is varied to obtain a constant punch force below the fracture limit [11, 21–22]. The method makes use of a closed-loop system, i.e., the BHF is based on the current value of the punch force. The closed-loop approach can also be applied on other parameters such as edge draw-in [23], wrinkling [24], thickness strain [13, 25–26], tangential force [25], or to improve the draw ratio, cup height, reduction of spring back, or to enhance shape fixability.

2 Conditions

Forming limit diagram was used for fracture prediction of Al1100. Each material has a unique FLD for each thickness and this FLDs are usually determined experimentally, and many materials, the FLDs available in the literature. Furthermore, formulas are available to calculate the plane-strain interception. The "Equations (1) and (2)" explained this idea. (FLD User's Conference Notes. 1991) [27].

\[
FLD_0 = \frac{n}{0.21} (23.3 + 3.59\tau_0) \quad n \leq 0.21 \quad (1)
\]

\[
FLD_0 = (23.3 + 3.59\tau_0) \quad n \geq 0.21 \quad (2)
\]

In sheet-form, the FLD is approximated by four constants. These constants are:

a) Plane-strain interception, \( FLD_0 \)
b) Slope of the line approximating the FLD in the negative minor strain region \( (S_1) \)
c) Slope of the line approximating the FLD in the positive minor strain region \( (S_2) \)
d) Band with separating the safe and fracture regions, \( (B) \)

from Equation 1 and slopes are estimated from similar curves in the literature (ASM, 1988) [28]. the FLD for Al1100-O is shown in Fig. 2.

Appropriate thickness distribution is obtained by using the following counter-pressure profile (shown in fig. 5) which is adopted from experimental work (Zhang et al, 2000) (see Fig. 3) [29]. Several finite element simulations with maximum counter-pressure profile, 5Mp were performed and for each finite element simulation run, the forming depth at which the sheet would start to failure was recorded.

Table 1 shows the hydromechanical deep drawing process parameters and material properties that used in simulation. Several
### Table 1: Process parameters and material properties for Al1100-o [30]

<table>
<thead>
<tr>
<th>Number</th>
<th>Parameters</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Blank diameter, (mm)</td>
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</tr>
<tr>
<td>2</td>
<td>Thickness, (mm)</td>
<td>0.812</td>
</tr>
<tr>
<td>3</td>
<td>Young’s modulus, E (Gpa)</td>
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<td>4</td>
<td>Strain hardening exponent, n</td>
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<td>5</td>
<td>Strength coefficient, K</td>
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<td>6</td>
<td>Yield stress (Mpa)</td>
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<tr>
<td>7</td>
<td>Punch Displacement (mm)</td>
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<tr>
<td>8</td>
<td>Anisotropy, R₀⁰</td>
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<tr>
<td>9</td>
<td>Anisotropy, R₁₅₀</td>
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<tr>
<td>10</td>
<td>Anisotropy, R₉₀</td>
<td></td>
</tr>
</tbody>
</table>

### 3 Finite element simulation

Modeling of hydromechanical deep drawing process was developed using Abaqus/CAE and commercial explicit software of Abaqus was used. In the FE model, the pressurization was modeled by prescribing values of hydrostatic pressure on the surface of the sheet, whilst modeling was effected using shell elements S4R for 3D model. The path of the counter-pressure and blank holder force were defined using “AMPLITUDE” which employs forming-time as a variable. The punch, blankholder and drawing die were modelled using rigid surface-elements R3D4 for 3D model. Coulomb friction was assumed for contact analysis. Fig. 4 shows simulated model by Abaqus/Explicit.

![Simulated model by Abaqus/Explicit](image)

The idea of the present investigation is to apply a BHF profile similar to that obtained using the “fracture limit BHF method”. This type of BHF profile is assumed to have the advantage of ensuring a fast pressure build-up in the initial stages of the deep drawing. Stretching at the final stages of the drawing to suppress wrinkling and improve shape fixability is also feasible. For the material between the draw die and the punch, the axial stress is higher with higher punch force, and the circumferential stress lower; hence, the tendency for wrinkling is diminished. When the punch force has maximum value, the circumferential stress is low and the tendency for wrinkling in the flange is reduced. The BHF can therefore be held at a lower level in the middle part of the drawing than the BHF level needed to suppress wrinkling at the beginning or final stages of the drawing. Near the final stage of the drawing, most of the deformation occurs in the flange with large circumferential stresses (axial stress reduced), and wrinkling in the flange is likely to occur.

The closed-loop control method can be adapted to the change of material and process conditions, and a more robust process can be made. The proposed form of controlling the BHF is given below, and a schematic of the proposed BHF profile is shown in Fig. 5.

![Schematic of the proposed VBHF closed-loop method and parameters](image)

\[
VBHF = VBHF_{\text{Min}} + \left( F_{\text{estimate}} - F_P \right) \left( \frac{VBHF_{\text{Range}}}{F_{\text{estimate}}} \right)
\]

There are 2 constants to be used with this expression. An estimate of the maximum punch force (\(F_{\text{punch, est}}\)) for the drawing have to be estimated in advance. For this variable BHF curve, the other 2 constants control the limit of the BHF profile: a minimum BHF level (VBHF min) and the maximum BHF range (VBHF range). This is illustrated in Fig. 6, setting a BHF range of 104 kN and minimum of 24 kN.
4 Results and Discussion

Maximum thinning for all blank holder force suggested are seen in Fig. 7. The maximum thinning has reached 20% and fracture was predicted at this point. The results showed that using a constant BHF of 104 KN, a maximum thinning occurred and the cup fractured at a punch travel of 16mm. and when using a constant BHF of 60KN, the cup fractured at a punch travel of 23mm, and also when the process performed with a constant BHF of 24KN, sever wrinkling in the flange area and die radius occurred.

Based on these results it was apparent that using a constant BHF, it would not be possible to form a blank into a cup with any defect. The BHF should be varied to prevent wrinkling and, at the same time, avoid fracture, but using VBHF, it was possible to prevent wrinkling and fracture completely, in addition, by varying the BHF it was possible to keep the maximum thinning around 10% (in cup wall region) and complete the deformation (see figures 8-10).

5 Conclusions

In the work presented, the hydromechanical deep drawing process with use of a variable blank holder force is investigated numerically. Inspired by the work done by Manabe et al. [26], a profile for the blank holder force is proposed. This profile, where the minimum in the blank holder force appears when the punch force is maximum, is obtained using a closed-loop approach. In this approach, the blank holder force is based on the current punch force, i.e., an in process control.

The material used for the blank is Al1100 and, successful cups have been drawn, also the results
showed that by varying the BHF based on punch force, it was possible to reduce the maximum thinning to around 15%.

Based on this observations, it must be concluded that, due to large variations in force are required in a short time, BHF profile is must to have the advantage of ensuring a fast pressure build-up in the initial stages of the deep drawing. Thus a pneumatic-based BHF system cannot be recommended where large variations in force are required in a short time. Applying the “fracture limit BFH method” may require a variation in the BHF of a factor of 3–4 times the punch force in order to control the level of the punch force. A system able to estimate the punch force, based on parameters gathered in the initial stage of the deep drawing, may be useful to be optimizing the deep drawing process. This approach has been applied for the conventional deep drawing process.

References: