EQUIVALENT DRAWBEAD MODEL IN FINITE ELEMENT SIMULATIONS

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ABSTRACT

In 3D simulations of the deep drawing process the drawbead geometries are seldom included. Therefore equivalent drawbeads are used. In order to investigate the drawbead behaviour a 2D plane strain finite element model was used. For verification of this model experiments were performed. The analyses showed that not only the restraining force should be applied but also the strain changes. The effects of the restraining force and the strain change were implemented in an equivalent drawbead. The effect of using the equivalent drawbead is demonstrated with a few examples.

1. INTRODUCTION

Drawbeads are widely used in deep drawing processes to control the flow of the blank during the forming operation. In 3D finite element simulations the drawbead geometries are seldom included because of the small radii. These small radii require a very large number of elements and therefore large computer time. For this reason equivalent drawbeads are used.

Equivalent drawbeads are defined on the tool surface; at the equivalent drawbead a restraining force acts. This restraining force is assigned through a 2D simulation of the drawbead or through an experiment. This restraining force reaches its steady state value when a part of the sheet has been pulled entirely through the bead (Cao,1993). However, in most of the finite element programs the drawbead force has been taken as the steady state value.

During the flow of the material through a drawbead a process of bending and unbending occurs. The strain distribution changes and the material usually becomes thinner (Wouters,1994)(Carleer,1994). Modelling drawbeads by only applying an additional restraining force does not incorporate the modified material properties. For this reason an equivalent drawbead was developed which incorporates also the effects of sheet thinning and the change of the strain distribution.

In the next section of this paper a short overview of the drawbead behaviour is given. In order to obtain more insight in the drawbead behaviour a 2D analysis was carried out. This analysis gave information on the drawbead restraining force and the strain changes. To verify the 2D analysis a set of experiments was performed (Carleer,1994). With the results of the 2D analysis an equivalent drawbead was developed.

In section three the equivalent drawbead will be focused on. The equivalent drawbead model incorporates not only the restraining force but also the effects of sheet thinning. The influence of also applying strain changes will be shown in some examples in section four.

2. 2D DRAWBEAD MODEL

In this section the drawbead behaviour is studied. Therefore a 2D plane strain analysis was

carried out. An experimental set-up was built for verification of this model. out. One drawbead geometry and one sheet material will be focused on. The dimensions of the drawbead are depicted in 1. The material properties of the sheet material are:
Ludwik value (C) = 551 N/mm²
n-value (n) = 0.230
initial yield stress = 149 N/mm²
blank thickness = 0.7 mm

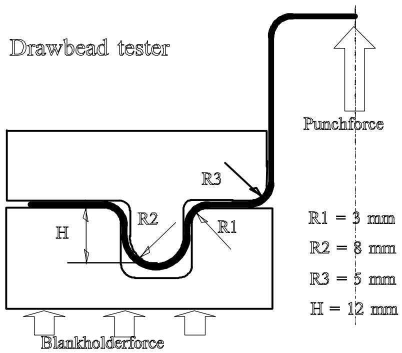

FIGURE 1. EXPERIMENTAL SET-UP OF THE DRAWBEAD TESTER

2.1. 2D Plane Strain Analysis

The analysis was carried out using the implicit finite element code DiekA which has been developed at the University of Twente in co-operation with Hoogovens Research & Development. This code has the possibility to use a mixed eulerian lagrangian formulation (Huétink,1986). In this formulation the material displacement and the grid displacements are decoupled. In this 2D drawbead model the mesh is fixed in flow direction, perpendicular to the flow the mesh is free to move. The advantage of this formulation is that the grid refinements remain at their place and the effects of sheet thinning can be described as well. Besides there is no need to model a large mesh in contrast with a lagrangian formulation where the sheet can be pulled out of the drawbead.

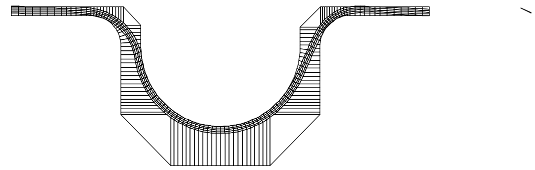
FIGURE 2. FINITE ELEMENT MESH 2D ANALYSIS

The sheet was modelled with four node bi-linear plane strain elements. The number of elements in thickness direction was four and the total number of elements in the strip was 400. For contact description special contact elements were used (Huétink,1989). The friction coefficient was 0.16. The mesh of the model is depicted in 2. The contact elements are also depicted.

In 3 the calculated force to pull the sheet through the drawbead as a function of the sheet displacement is printed. As can be seen the pulling force reaches its stationary value at 30 mm displacement. The tangential strain of the sheet at the exit of the drawbead is also depicted in 3. The stationary value of the tangential strain is reached after 35 mm displacement. Due to the plane strain assumption and the almost incompressible material behaviour this is almost (except for the sign) the thickness strain.

2.2. Experimental Verification

At Hoogovens Research & Development the experiments were performed at a fully equipped Erichsen press for verification of this 2D model. The experimental set up of the drawbead tester is shown in 1. The punch speed was kept constant at 3 mm/s and the blankholder was fixed at a constant clearance of 0.7 mm, which was the original sheet thickness. The punch force was recorded during the experiment and after performing the experiment the thickness was measured at a few locations of the strip.

First the thickness distribution is compared. At the entrance of the drawbead the thickness does not change. At the exit of the drawbead the thickness strain for the experiment was -0.08, and for the 2D analysis a thickness strain of -0.085 was found. Also in the drawbead the measured and calculated thickness strain agreed fairly well.

In order to compare the stationary value of the experimental punch force with the FE calculation an additional force should be added to the calculated pulling force. This additional force is caused by the 90° bending at the die radius. The force needed for this 90° bend was calculated separately using the changed thickness and strain distribution. The measured punch force was 106 N/mm and the calculated punch force was 105 N/mm and we conclude that these two punch forces agree very well. Therefore we can accept that the calculated drawbead restraining force is correct.

Concluding we can say that the 2D plane strain model is an accurate model to gain information about the drawbead strain and the drawbead force. This information will be used in the equivalent drawbead which is described in the next section.

3. EQUIVALENT DRAWBEAD

The equivalent drawbead is defined as a line or a zone on the tool surface. If an element passes or cuts the equivalent drawbead line a restraining force acts on that element. But this restraining force is not enough to describe the whole drawbead behaviour. So, besides a restraining force also an additional strain should be added to the element.

The drawbeads are positioned at places where the material should not flow into the die too fast. When the material flows through a drawbead the normal component to the drawbead line gives all the strain and the force. The tangential component of the material flow does not give any contribution to the drawbead strain and force. Therefore the material

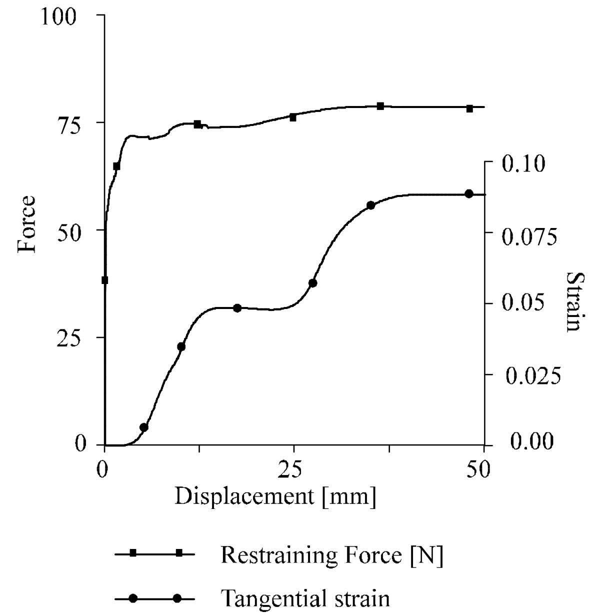

FIGURE 3. NUMERICAL RESULTS 2D ANALYSIS

flow, v, will be split in a normal, v_n and a tangential component, v_t, see 4. For the equivalent drawbead only the normal component will be taken into account. The drawbead coordinates will be defined as the x_{db} Error! Switch argument not specified.-axis normal to the drawbead and the y_{db} Error! Switch argument not specified.-axis tangential to the drawbead. The y_{db} Error! Switch argument not specified.-axis is the plane strain direction of the 2D analysis.

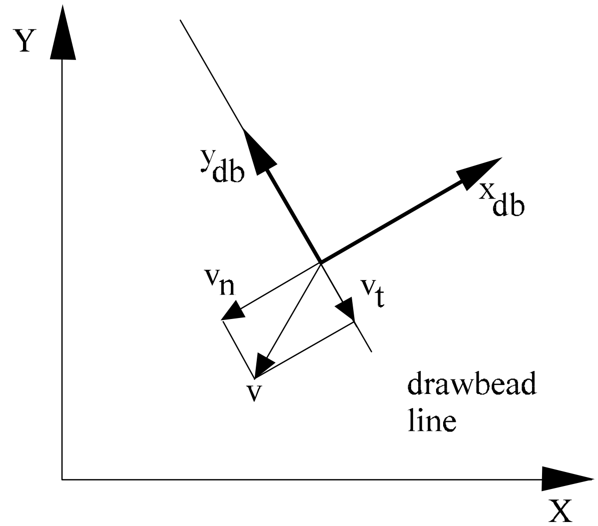

FIGURE 4. DRAWBEAD COORDINATE SYSTEM

3.1. Drawbead restraining force

The restraining force acts normal to the drawbead line opposite the normal material flow. This additional force is taken into account at the right hand side of the finite element equations as a body force. The force is equally divided among the two nodes of the element side which cuts the equivalent drawbead.
The restraining force is calculated by integrating the drawbead force per unit width over the length of the elements in the drawbead line:

The restraining force is history dependent, its value is a function of the material which already passed the drawbead. The model is fed by an added force which is a curve fit from the drawbead force per unit width, which in turn is gained from a 2D drawbead analysis or from an experiment. As can be seen in 5 the dotted line shows the curve fit of the drawbead restraining force from the 2D analysis. The force increases exponentially until the steady state value is reached

$\underline{K}$

3.2. Drawbead strain

The implementation of the drawbead strain needs more attention. The strain to be added is also history dependent. The strain is a curve fit from the drawbead strain gained from a 2D drawbead analysis or an experiment. As displayed in 5 the dotted line shows the curve fit of the drawbead strain from the 2D analysis. To implement this additional strain a little work needs to be done. The drawbead gives an extra stiffness term in the finite element equations:
The left side of the equation can be split:

$(\underline{K}$

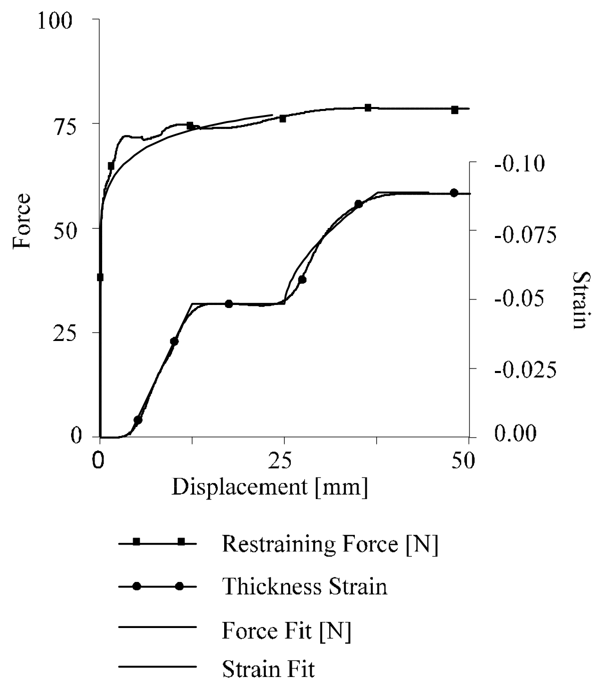

FIGURE 5. DRAWBEAD FORCE FIT AND STRAIN FIT

or:

$$\underline{K} \bullet \Delta\underline{u} = \Delta\underline{F} - \underline{K}_{db} \bullet \Delta\underline{u} \qquad (5)$$

The drawbead stiffness term can be rewritten in drawbead stresses:

$$\underline{K} \bullet \Delta\underline{u} = \Delta\underline{F} - \int_V \underline{B}^T \bullet \underline{s}_{db}\, dV \qquad (6)$$

The only thing that must be done is an estimation for the drawbead stresses. The starting point for the stress estimation is the configuration as displayed in 5.

The material passes the drawbead line and becomes thinner. Because of the plane strain assumption in y_{db} Error! Switch argument not specified. direction the material only becomes longer in x_{db} Error! Switch argument not specified. direction. The thickness of the material is very small with respect to the other dimensions. So, a plane stress state is assumed. In order to find the drawbead stresses the following equations must be solved:

$$\dot{\underline{\underline{s}}}_{db} = \left[\underline{\underline{E}} - (1-h)\underline{\underline{Y}}\right] : \dot{\underline{\underline{e}}}_{db} \quad ; \quad \underline{\underline{E}} = \text{elastic tensor},\ \underline{\underline{Y}} = \text{yield tensor},\ h = \text{hardening rate} \qquad (7)$$

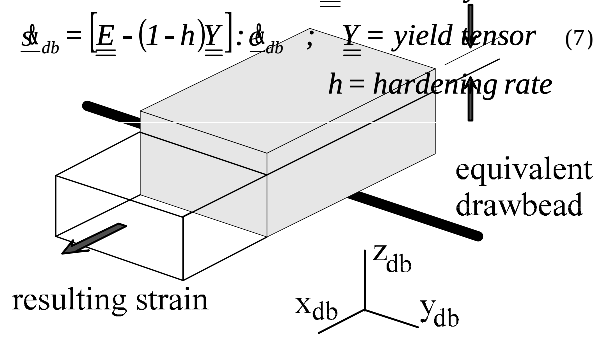

FIGURE 6. STARTING POINT STRESS ESTIMATION

As mentioned above the boundary conditions are:
With the boundary conditions 8 equation 7 reduces to three equations with three unknowns. The components of the elasticity tensor can be written as:
In which E is the modulus of elasticity and υ is Poisson's ratio. Second the yield tensor needs attention. A general expression for the yield tensor is:
in which f Error! Switch argument not specified. is the yield function. Because of the incompressibility and the plane strain assumption:
Working out equation 10 with the assumption of equation 11 the components of the yield tensor are:

[E

$$
[Y_{ij}] = \begin{bmatrix} G & 0 & -G \\ 0 & 0 & 0 \\ -G & 0 & G \end{bmatrix} \qquad (12)
$$

Third an expression for the hardening rate is defined:

$$
h = \frac{f}{f - \frac{\partial f}{\partial \underline{s}} : \underline{\underline{E}} : \frac{\partial f}{\partial \underline{s}}} \quad ; f = -4(R+1)^2 s_{yield}^{\;2} \frac{\partial s_{yie}}{\partial e} \qquad (13)
$$

In this definition all the components are known values of our stress state. So equation 7 can be solved by using the known expressions 9, 12 and 13. The stresses s_{dbx} Error! Switch argument not specified. and s_{dby} Error! Switch argument not specified. can be used to describe the drawbead strain according ot equation 6.

Summarizing the equivalent drawbead model, it exists of two components, 7. First, the prescribed force which restrains the element of sliding too fast through the drawbead. Second, the prescribed strain which elongates the element and in this way the element becomes thinner. These two components are added up to give the complete drawbead description.

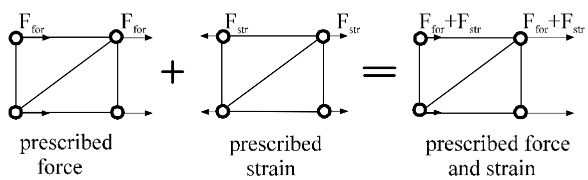

FIGURE 7. DRAWBEAD MODEL

4. APPLICATIONS

In this section three tests for the equivalent drawbead model are performed. The first test is the pulling of a strip through a die and blankholder. The second test is the deepdrawing of a strip. The third test is the deepdrawing of a rectangular product.

4.1. *Simple Strip*

This test for the equivalent drawbead is pulling a strip through a die and a blankholder as described in 8. Due to the low blankholder force the strip is only translating. In addition on the die/blankholder an equivalent drawbead is defined. The only resistance to sliding is caused by the equivalent drawbead.

In this test two different drawbead descriptions were used. In the first simulation only a restraining force of 90 N per unit width is applied. In the second simulation besides the restraining force also an

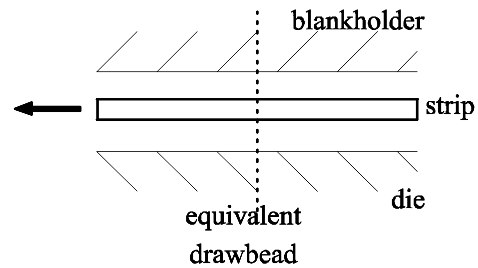

FIGURE 8. SIMPLE STRIP TEST

additional strain of 0.15 is applied. The equivalent drawbead is defined at original strip coordinate 0 mm. The strip is translated 50 mm. So, the equivalent drawbead ends at original distance 50 mm. The obtained thickness strain distribution of both simulations is shown in 9.

Comparing the two simulations there is no difference in the pulling forces. As we expect the strain distribution differs significantly. When neglecting the strain caused by passing the drawbead, the thickness strain is only 0.015. When including the additional strain caused by the drawbead, the thickness strain is about 0.15. It can also be seen that the elements which passed the drawbead are elongated.

4.2 Strip Drawing

The next test is a strip drawing simulation. The set-up is almost identical to the drawbead experiment except for the drawbead geometry. For this simulation also three node membrane elements are used. The equivalent drawbead is defined as a line on the die/blankholder. The drawbead force and the drawbead strain are both history dependent. The steady state value of the drawbead restraining force was 90 N, the steady state value of the strain was 0.15. The shape of the fits were the same is in 5. In 10 the deformed mesh and the thickness strain are printed. When looking at the deformed mesh the total length of the strip is about 104 mm, the punch rounding is at coordinate distance 35 mm and the die rounding at coordinate distance 75 mm. The equivalent drawbead is situated at coordinate distance 90 mm.

In the first simulation only the drawbead restraining force is applied, the stripe line. This results in a thickness strain under the punch of 0.05. In the second simulation both restraining force and drawbead strain are included, the full line. The strain under the punch is much lower but in the rest of the strip the strain is higher. Also the strain characteristic of 5 can be seen. At coordinate distance 60 mm a more or less constant strain level of -0.08 is seen, at coordinate distance 80 mm the strain level drops to -0.16. This latter simulation shows a strain distribution which is similar to the strain distribution found in the experiments.

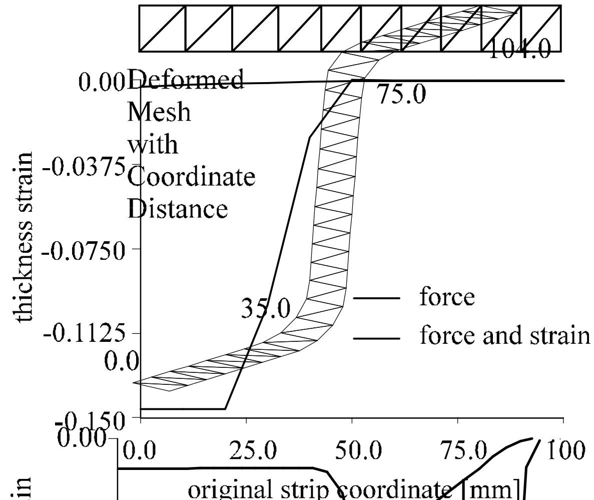

FIGURE 9. THICKNESS STRAIN DISTRIBUTION OF THE SIMPLE STRIP PROBLEM.

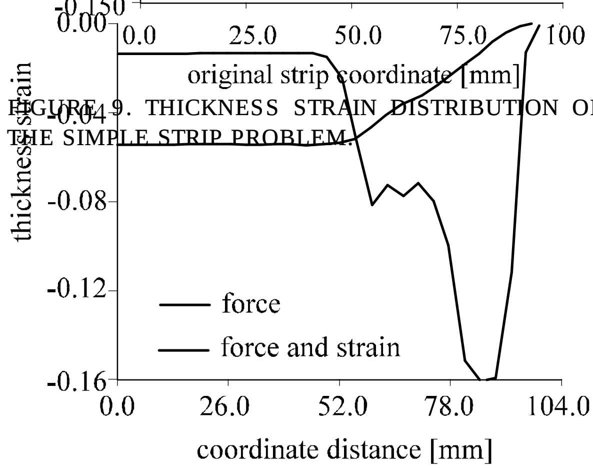

FIGURE 10. THICKNESS STRAIN DISTRIBUTION OF THE STRIP DRAWING SIMULATION.

4.3. Rectangular product

The third test is a deepdrawing simulation of a rectangular product. Because of symmetry only one quarter of the product was simulated. The dimensions of the blank and the tools as well as the position of the drawbead are shown in 11.

Three simulations of the rectangular product are performed. For the simulation three node membrane elements are used. The first simulation is without a drawbead. The second and third simulation are with a drawbead. For the drawbead description the equivalent drawbead is used. In the second simulation only the drawbead restraining force is applied. In the third simulation both restraining forces and strain changes are applied. The drawbead characteristics of 5 are used.

In 12 the flange shape of the three simulations as well as the original blank shape are shown. It can be seen that the flange shape of both simulations with drawbead is almost the same. Comparing these two simulations with the simulation without a drawbead the following remarks can be made. The draw-in of the simulations with drawbead at the position of the drawbead is less than the draw-in with the simulation without drawbead. At the y-axis it is the other way around. The tip of the blank is rotated due to the different draw-in for the simulations with the drawbead.

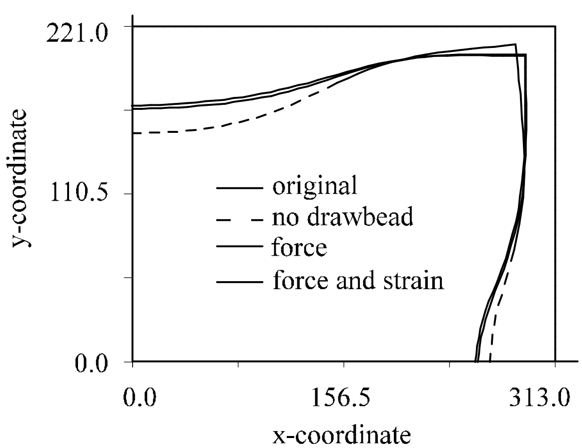

FIGURE 12. FLANGE SHAPES OF THE DIFFERENT SIMULATIONS OF THE RECTANGULAR PRODUCT.

The thickness strain distribution along the y-axis, which is the axis with the drawbead, is printed in 13. The simulation without a drawbead, the stripe line, shows a flat and smooth characteristic. In the simulations with the drawbead more thickness reduction is found. Under the punch, coordinate distance 0 mm till 100 mm, a constant strain is found. For the simulation with only the force more thickness reduction is found than in the simulation with both force and strain. In the upright side till the equivalent drawbead, coordinate distance 130 mm till 200 mm, the simulation with force and strain shows more thickness reduction than the simulation

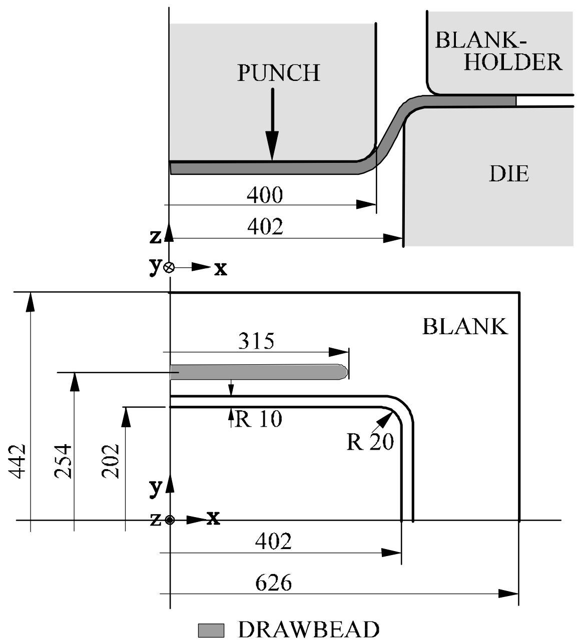

FIGURE 11. BLANK AND TOOL GEOMOTRY OF THE RECTANGULAR PRODUCT

with only a force. The differences are much smaller than in the strip drawing simulations. One reason for this difference is the less freedom of the elements in the rectangular product. A second reason is the reduced convergence speed because of the equivalent drawbead with both force and strain. This means that with the same relative unbalance the absolute unbalance in the drawbead area is higher.

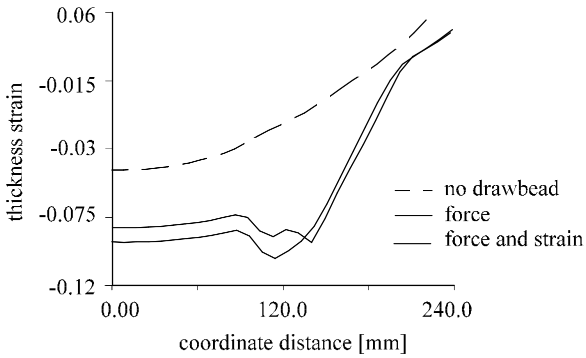

FIGURE 13. THICKNESS STRAIN DISTRIBUTION RECTANGULAR PRODUCT.

5. CONCLUSIONS

The 2D plane strain model works well to study the drawbead behaviour. The agreement with the experiments is very good. So we have a reliable tool to predict the effects of a drawbead. The 2D analysis has been used to develop a 3D equivalent drawbead.

This 3D equivalent drawbead includes both the restraining forces and the strain changes. Several test were performed, a simple strip test, a strip drawing test and a rectangular product test. For uncomplicated problems like the simple strip and the strip drawing the strain changes due to passing the drawbead are not described well only applying the drawbead force in the equivalent drawbead. The equivalent drawbead in which the force and strain effects were included gives a good description of the real drawbead. For the rectangular product applying both force and strain compared to only force gives almost no differences.

With this equivalent drawbead it is possible to include drawbeads in an accurate way.

6. ACKNOWLEDGEMENTS

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