3-D MODELLING OF SHEET METAL SHEARING

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Abstract

In sheet metal cutting processes, like guillotining and slitting, the sheet is cut progressively from one end to the other. This means that these processes can be seen as three-dimensional stationary processes. A finite element model is developed for the calculation of the steady state of such processes. The Arbitrary Lagrangian Eulerian method is used, because this method is very suitable for stationary calculations with moving free surfaces. The position of the nodes on the surface is adapted every step using a limited Lax-Wendroff convection scheme. Results of a guillotining simulation are shown.

1 INTRODUCTION

A guillotine-type shear (Figure 1) has two straight blades. The shearing angle \( \alpha \) is the angle between the upper and lower blade. When the upper blade is inclined (\( \alpha > 0^\circ \)) the sheet is cut progressively from one end to the other, which is a stationary process. In case of parallel blades (\( \alpha = 0^\circ \)) the sheet is cut at once and the process is transient.

While the nett result for the sheared edge is the same in both cases, there are some differences between the two. The force required to cut the sheet is decreasing with increasing shearing angle, since only part of the sheet is cut at a moment. But also the quality of the sheared products is deteriorating with increasing shearing angle \( \alpha \). The sheet has to bend to conform to the inclination of the blade. This causes some irregularities in the sheet, especially for small off-cuts (Figure 2). Therefore a compromise has to be made between required force and the quality of the cut sheet. In practice the shearing angle varies between 1°–3°.

The sheet undergoes elastic and plastic deformation when the upper blade is forced down. After penetrating to a specific part of the thickness of the sheet the unpenetrated part fractures and the cut is completed. These phases occur sequently in orthogonal shearing. Guillotining however is a steady state composite of these phases. The size of the different phases depends on the material characteristics, clearance and blade geometry.

The knowledge of the influence of the process parameters on the proces is mainly empirical [?]. The objective of this study is to gain more insight in these processes. Therefore a finite element model is developed by which the influence of the parameters on the shearing process can be studied. The results should contribute to a better process control.

2 MODELLING SHEARING PROCESSES

For a complete simulation of the shearing process all phases should be described properly. This means that large deformations with history dependent material behaviour, contact and ductile fracture must be incorporated in the model.

Eulerian formulations are capable of handling large material deformations, but are less suited for the description of history dependent material behaviour and the movement of free surfaces. In Lagrangian formulations path dependent material properties and the movement of free surfaces can easily be described, but
this formulation can fail in simulating forming processes when the element grid becomes too much distorted. Therefore the Arbitrary Lagrangian Eulerian formulation (ALE, discussed in section ??) is used. With such a formulation it is possible to handle history dependent material behaviour, to follow free surfaces and to keep the mesh regular.

The sheets are finally seperated by a ductile fracture process. Again there is a difference between stationary and transient shearing processes. In the transient case no cracks are initially present. After some punch penetration a crack initiates, which will subsequently grow leading to complete separation. Some different approaches for the simulation of ductile failure in shearing have been presented by [?], [?], [?] and [?].

In the stationary case the crack growth is stable and an initial crack front can be modelled. The crack front is a free surface, which position depends on some fracture criterion. With the ALE method and a fracture model it should be possible to adapt the crack front from a initial guess to its steady state position. However this phase is not yet incorporated in our model.

3 ALE METHOD

The ALE method is implemented in DiekA, a finite element code developed at the University of Twente. In the ALE formulation mesh and material displacements are independent. First an Updated Lagrangian step is done to calculate the material displacements. Next the grid displacements are determined using the strategies in section ??.

3.1 Definition of a new mesh

When determining the new positions of the nodes, two kind of nodes can be distinguished. Nodes on the surface, which should remain on the surface and internal nodes which can moved freely in the material as long as a good element shape is preserved. In the calculations presented in this paper, internal nodes are spatially fixed.

The geometry is meshed in such a way that the initial mesh on the surfaces is regular. During the simulation the surface mesh is kept regular. The grid is fixed in flow direction (x-direction). Perpendicular to the flow direction (in the yz-plane) the grid is following the free surface.

Determining new nodal positions of surface points can be seen as a convection problem. This convection is done in two steps. First convection along a gridline in the flow direction is carried out. This is illustrated in Figure ??.

Figure 3. Convection of nodal coordinates

\[ y_i^{n+1} = y_i^n - C \left( y_i^n - y_{i-1}^n \right) - \frac{1}{2} C (1 - C) \left[ \psi(r_{i+1/2})(y_{i+1}^n - y_i^n) - \psi(r_{i-1/2})(y_i^n - y_{i-1}^n) \right] \]  

(1)

The Courant number \( C \) is a measure for the relative displacement between the material and the mesh. \( l_c \) is a characteristic element length.

\[ C = \frac{V \Delta t}{l_c} = \frac{\Delta x}{l_c} \]  

(2)

The van Leer limiter \( \psi(r) \) stabilizes the Lax-Wendroff scheme when the gradients are large.

\[ \psi(r) = \frac{r + |r|}{1 + |r|}; \quad r_{i+1/2} = \frac{y_i^n - y_{i+1}^n}{y_i^n - y_{i-1}^n}; \quad r_{i-1/2} = \frac{y_{i-1}^n - y_i^n}{y_i^n - y_{i-1}^n} \]  

(3)

The same procedure is applied for the calculation of the new z-coordinate.

The application of this scheme is illustrated with a test problem. The initial mesh is shown in Figure ??.
the described scheme. All other nodes are spatially fixed. In Figure 4 the results are shown after some steps. From this can be concluded that the scheme used is stable but also shows some diffusion.

After the convection in flow-direction for all nodes is completed, a second convection step perpendicular on the flow direction (in the yz-plane) will be done. Herein the nodes are kept regularly spaced. The Courant number and direction of convection are determined from the material displacements in the Lagrangian step. This method can be refined using the ideas of Ponthot[?].

4 SIMULATION RESULTS

The results of a 3D guillotining simulation are presented. The shearing angle is 5.7°. An elastic-plastic material model is used, with a Von Mises yield criterion for the plastic flow. Hardening is described with the extended Nadai formula.

\[
\sigma_y = \sigma_0 + C(\varepsilon_0 + \varepsilon_p)^n
\]  

(4)

For the contact with the rigid tools a penalty method is applied[?]. The horizontal movement of the sheet perpendicular to the flow direction is suppressed at the boundaries.

Figure 5 gives the initial mesh for the stationary simulation (tools are not drawn). The material flows from the left to the right through the mesh. The tools are moving with the same speed as the material flows in. The calculation is continued until a steady state is reached. The position of the nodes on the surface is adapted every step with the algorithm of section ?? . The difference between the initial and steady state geometry is best seen in the process zone.

| \(\varepsilon_0\) | 7.1 \times 10^{-3} |
| \(\sigma_0\) | 15.7 MPa |
| C | 565.3 Mpa |
| n | 0.2589 |
| E-modulus | 206 MPa |
| \(\nu\) | 0.3 |

Table 1. Material properties

| Sheet thickness | 1 mm |
| Sheet width | 4 mm |
| Radii | 0.01 mm |
| Clearance | 10% |
| Friction coefficient | 0.2 |

Table 2. Tool and Sheet geometries

In Figures ?? and ?? the steady state equivalent plastic strain and hydrostatic pressure are given for a cross section with a tool penetration of 50% sheet thickness. Between the radii of the blades a zone of large strains combined with hydrostatic tension has developed, which is the place where the sheet will fail. The
Figure 6. Results for cross-section at 50% penetration

The total number of 8-node elements in this simulation is 5088, which is 318 elements per cross-section. These 3-D calculations take even with an iterative solver much time to solve, therefore calculations with finer meshes are not carried out.

The influence of the shearing angle can be illustrated with Figure 7. The stresses in flow-direction form two bending moments. These bending stresses are sensitive for the applied boundary conditions. The way the cut-off sheet is clamped influences the irregularities in Figure 2 [?]. In practice the cut-off part is clamped much less than in our simulation and the sheet will bend and twist much more. This means for the calculation that it is not sufficient anymore to keep the internal nodes spatially fixed.

5 CONCLUSIONS

From the presented results can be concluded that the ALE method is very suitable for simulation of the stationary shearing processes. Free surfaces can be followed with the procedure from section ?? A method for moving internal nodes should be implemented to obtain a better internal element mesh and to handle other (less constrained) boundary conditions. For a complete simulation an algorithm is needed that describes ductile failure.

Since 3-D calculations consume much more computer time than plane strain calculations it should be investigated whether the influence of some parameters can be studied as good in plane strain as in full 3-D.

REFERENCES