

NUMERICAL AND PHYSICAL MODELLING IN FORMING

J.Huétink, A.H.van den Boogaard, H.J.M.Geijselaers ,V.T. Meinders

Netherlands Institute for Metal Research,
University of Twente, Faculty of Mechanical Engineering
PO box 217, 7500 AE Enschede, the Netherlands

Abstract: An overview will be presented of recent developments concerning the application and development of computer codes for numerical simulation of forming processes. Special attention will be paid to the mathematical modeling of the material deformation and friction, and the effect of these models on the results of simulations.

Keywords: FEM, Forming, Material, Contact, Friction

1. Introduction

Production and adaptation of forming tools is a costly business. When dealing with decisions in this field, production engineers and designers often require some guidance. Experience and insight are certainly indispensable. Fruitful use of numerical analysis techniques is possible for the following purposes.

- New processes and techniques can be studied for their feasibility even before any tool is produced.
- The trial and error design of tools and processes can be guided by the results of numerical sensitivity studies.
- Troubleshooting and optimisation of existing processes can be performed through numerical analyses.

Further development of the simulation algorithms is necessary to meet requirements of accuracy and computation time. Some subjects require special attention.

- Designers don't want to wait for several hours or even days to get answers on their questions. Hence rapid solution methods are necessary.
- In most metal forming processes changing contact between tool and blank occurs. Contact algorithms are highly non-linear. Accuracy and reliability of simulations strongly depend on the modelling of contact. Calculation speed is generally reduced due to the poor performance of the contact algorithm.
- Application of numerical simulation in an industrial research environment requires a fast and reliable handling of model information. User friendly interfacing with design codes (CAD) is necessary with a minimum on manual operations.
- Mathematical material models must be able to describe the key features of the forming process e.g. large deformations, anisotropy, temperature dependency, and springback.
- Numerical instabilities must be avoided yet physical instabilities should be predicted correctly.

A classification of forming processes can be made with regards to the numerical modelling features that are required. Processes are divided in:

- manufacturing of discrete products and
- continuous or semi continuous manufacturing.

For the first class of processes a Lagrangian type of numerical simulations is appropriate whereas for the second class an Eulerian type of approach is more suitable. In both classes we can distinguish processes with moderate deformations and processes with large deformations. When large deformations occur in a Lagrangian type of simulation, the finite element mesh may be very much distorted during the simulation, and remeshing is indispensable. Besides, in processes as forging and rolling thermal effects cannot be neglected generally. In sheet metal forming processes only moderate deformations occur usually, and temperature changes are small. Hence in simulations isothermal conditions are sufficiently accurate. When only moderate deformations occur remeshing is generally not required due to mesh distortion, however, remeshing may improve the accuracy, or may speed up the simulation.

2. Contact search algorithm

In forming processes contact between tools and workpiece is a dominating aspect. The tools are nowadays designed with the help of CAD packages. Most CAD packages can generate triangulated surface representations for use in FEM analysis. However, in FEM analysis adjacent elements must have matching vertices. Due to tolerances in the CAD-packages the triangulation suffers from defects. The mesher creates

large elements for flat areas and small elements where small radii occur which are not properly connected. An appropriate solution is to adapt the contact search algorithm for the lack of connectivity and the strongly differing aspect ratios.

If every element of the tool is checked for contact with every element in the workpiece, the analysis time increases quadratically with the number of elements. Therefore the contact search is split into two steps. First a fast global search is performed which delivers a number of tool elements where the contact may take place. Next a more time consuming local search is done to find the exact place of contact. The global search must handle the problem of non-adjacent elements and the varying element size. A global search has been developed based on the pinball algorithm introduced by Belytschko (see [1] and [2]) for contact impact problems.

2.1 Pinball search

The newly developed contact search algorithm uses the pinball algorithm. Around all tool elements as well as around all blank nodes imaginary spheres are created, designated as pinballs.

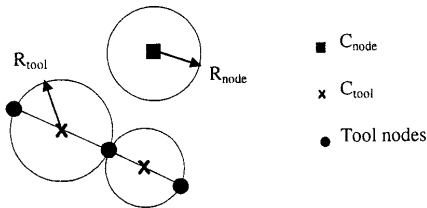


Figure 1 Principle of pinball search with the pinball's of the tool and the pinball of the blank node

The principle of the global search is to check the distance between the centres of the pinball of a blank node and the tool pinballs, see figure 1.

If penetration of these pinballs occurs, the element belonging to the tool pinball is further taken into account for the local search. If no penetration with any tool pinball is found, no contact occurs. The global search is very fast because there is only a comparison of co-ordinates. For more details about the contact algorithm see [6,7]

3. Friction

A commonly used friction model in numerical methods is the Coulomb friction model

$$F_f = \mu \cdot F_n \quad (1)$$

with F_f the friction force and F_n the normal force. The friction coefficient μ is an overall constant parameter. However, in reality μ depends strongly on local contact conditions.

According to Schey [3] there are several different contacts between the sheet and the tools. An accurate friction model needs a coefficient of friction, which depends on these local contact conditions. Therefore a Stribeck friction model has been developed which accounts for this dependency. In the work of Schipper [4] the coefficient of friction is presented as a function of the dimensionless lubrication number L :

$$L = \frac{h \cdot v}{p \cdot R_a} \quad (2)$$

with h the lubricant viscosity, v the velocity, p the mean contact pressure and R_a the CLA surface roughness. In figure 2 the friction coefficient is depicted as a function of the lubrication number, the generalised Stribeck curve.

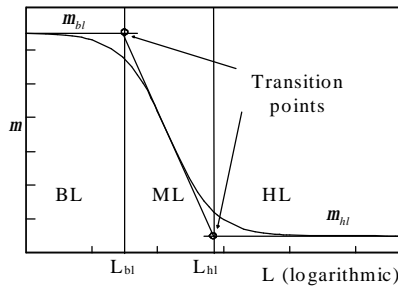


Figure 2. Generalised Stribeck curve

Three different zones can be distinguished. On the left hand side of the graph m has a constant high value. This is the boundary lubrication regime (BL). Contact is carried by the interacting surface asperities. On the right hand side the value of m is low, the load on the contact is fully carried by the lubricant. This is the hydrodynamic lubrication regime (HL). The region in between is called the mixed lubrication regime (ML). A curve fit is defined [5] to describe this frictional behaviour, see equation (3).

$$m = \frac{1}{2} \left(m_{bl} + m_{hl} + (m_{bl} - m_{hl}) \tanh \left(\frac{\log \left(\frac{L^2}{L_{bl} \cdot L_{hl}} \right)}{\log \left(\frac{L_{bl}}{L_{hl}} \right)} \right) \right) \quad (3)$$

with m_{bl} BL value of m , m_{hl} HL value of m , L_{bl} BL to ML transition and L_{hl} ML to HL transition. Details about the model can be found in [5,6,7]. Experiments were carried out on a testing device, which was especially designed for measuring the coefficient of friction for contacts operating under sheet metal forming conditions. The measured parameters are listed in table 2.

h	R_a	m_{hl}	m_{bl}	L_{hl}	L_{bl}
0.6	$1.0 \cdot 10^{-6}$	0.01	0.144	$5.1 \cdot 10^{-3}$	$2.8 \cdot 10^{-4}$

Table 2. Parameters for Stribeck friction model

To show the effects of the more physically based friction model a simulation of the deep drawing of a square cup is performed.

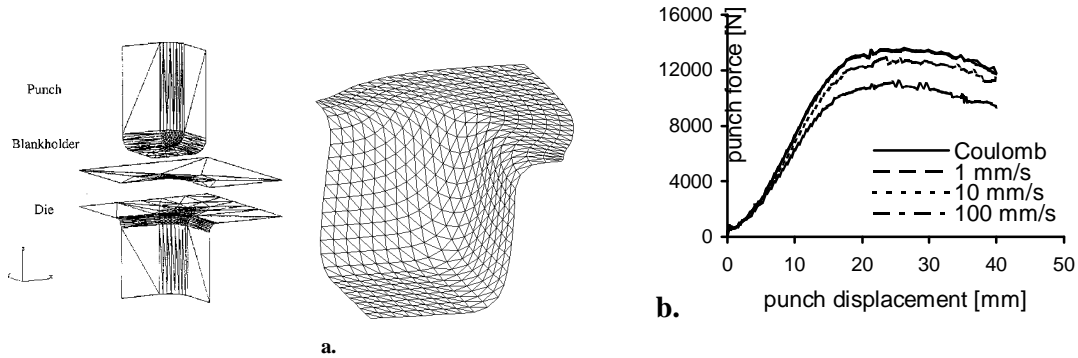


Figure 3a. Tool mesh, and Deformed mesh after 40[mm] deep drawing.

Figure 3b. Punch force versus punch displacement for four simulations.

Four simulations were performed. One with the Coulomb friction model ($m = 0.144$) and three with the Stribeck friction model with three different punch velocities, 1, 10 and 100 [mm/s]. Because of symmetry only a quarter of the cup is modelled. The deformed mesh after 40 mm deep drawing and the punch force are presented in figure 3. It shows that the punch force decreases from 14 [kN] at low velocity to 11 [kN] for Stribeck friction with a punch velocity of 100[mm/s]. The 1 [mm/s] and Coulomb simulation results coincide.

4. Mathematical material modelling

A commonly used yield criterion for anisotropic plastic deformation is the Hill yield criterion. This description is not always sufficient to accurately describe the material behaviour. This is due to the determination of material parameters by uni-axial tests only. Vegter [11] proposed a description, which directly uses the experimental results at multi-axial stress states. The yield criterion is based on the pure shear point, the uni-axial point, the plane strain point and the equi-biaxial point see figure 4.

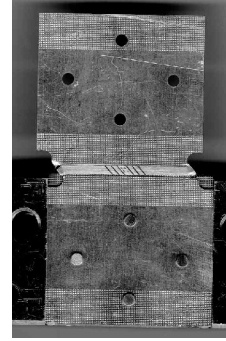
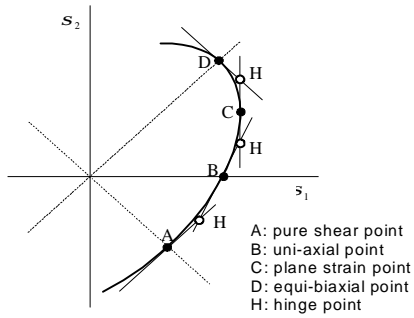


Figure 4a. The four reference points to construct the Vegter yield function. Figure 4.b Shear experiment

A yield surface is constructed using the reference points and the gradients in the reference points. This construction is performed with the help of Bezier interpolations [11].

Phenomena as the Bausschinger effect after load reversals or changing directions of deformation can be implemented by a double yield surface model. The inner surface is the actual yield surface and can translate in stress space whereas the outer surface serves for the determination of the hardening rate. More details are given by Van den Boogaard et al [24].

5 Deep drawing simulations

In sheet metal forming processes only moderate deformations occur usually. Remeshing is generally not required due to mesh distortion, however, remeshing may improve the accuracy, or may speed up the simulation. Local remeshing by subdivision of existing elements can be done with only little cost compared to global remeshing. Fig ?? shows an example of local remeshing based on a geometrical error estimator [25].

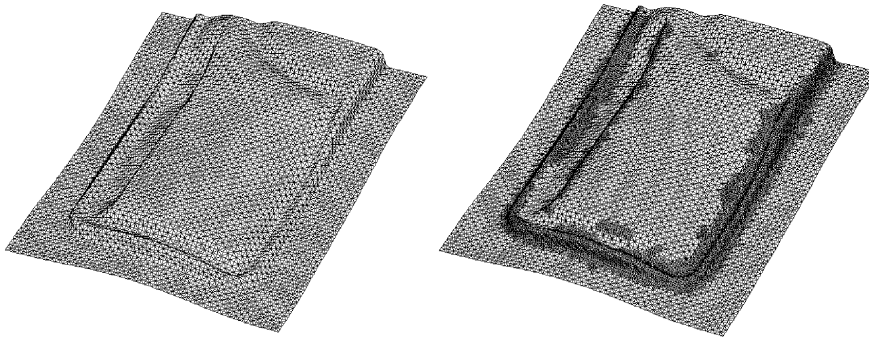


Figure 5 Local remeshing in deep drawing simulation

The occurrence of pleats and wrinkling in sheet metal forming is being investigated. Figure 6 shows some results of simulations predicting wrinkling. The prediction of pleats is rather sensitive for the contact (penalty) stiffness. A new contact algorithm based on optimization procedures for inequality constraints, is being investigated by G. Kloosterman [26] with the aim to improve the stability and accuracy of numerical problems including contact and friction.

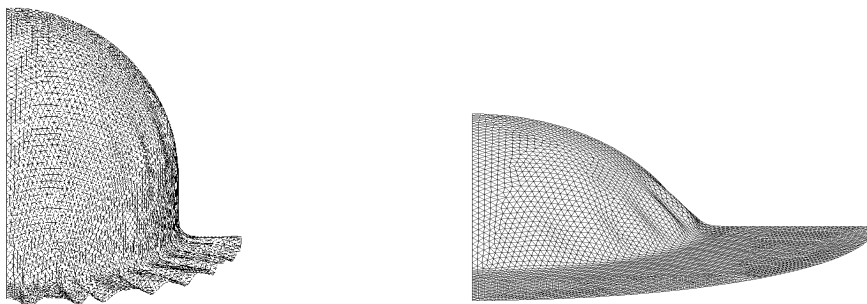


Figure 6 Primary and secondary pleats

In order to predict wrinkling a very fine mesh is required. If the mesh is too coarse, no wrinkling will be predicted if the wave length of the wrinkles is short. Adaptive remeshing based on wrinkling risk estimation as introduced by Selman et al, can avoid this problem. Remeshing is applied in those areas where the risk factor is high [27].

In deep drawing the material flow can hardly be controlled by the blankholder due to its global behaviour. The material flow can be influenced by drawbeads [8,9], see figure 7.

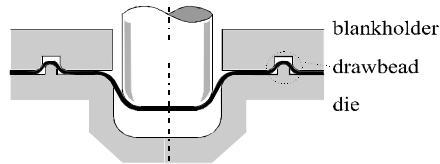


Figure 7 Deep drawing scheme including drawbeads

Modelling the real drawbead geometry requires a large number of elements due to the small radii in the drawbead. Therefore an equivalent drawbead model is developed in which the real geometry of the drawbead is replaced by a line on the tool surface [6,10]. When an element of the sheet metal passes this drawbead line an additional drawbead restraining force, lift force and a plastic strain are added to that element.

6. Rolling

Processes like rolling and direct extrusion can be regarded as (semi) continuous processes and require dedicated solution strategies. Classical solution methods based on the Lagrangian formulation are impractical due to excessive mesh distortions, while remeshing needs to be applied too frequently to maintain an accurate solution. The history dependent nature of the materials necessitates the use of an Eulerian or an Arbitrary Lagrangian Eulerian (ALE) formulation. A number of ALE formulations are reported in literature [12-22]. These ALE methods can be divided in *coupled* and *split* ALE formulations. In the first formulation the coupled Lagrangian-Eulerian equations are solved, see for instance the work of Liu et al [13]. In the second approach the Lagrangian-Eulerian equations are split and solved separately, see for example the work of Benson [14,15], Baaijens [16] and Huétink [12,17, 20]. A normal Lagrangian step is performed, followed by an explicit (purely convective) Eulerian. In this work the split ALE formulation is used. A result of hot rolling simulation is given in figure 8. Remarkable is the very inhomogeneous strain rate distribution in a steady state, see also [23]

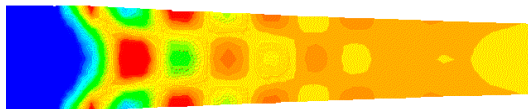


Figure 8 Strain rate localisation in rolling

Similar localisations are observed in wire drawing. In combination with an overall tensile stress this may result into the well known central bursting.

References

- [1] Belytschko, T. and M.O. Neal, Contact impact by the pinball algorithm with penalty and Lagrangian methods, *Int. J. Num. Meth. Eng.* **31**, 547-572, 1991
- [2] Belytschko, T. and I.S. Yeh, The splitting pinball method for contact-impact problems, *Comp. Meth. Appl. Mech. Eng.*, **105**, 375-393, 1993
- [3] Schey J.A., "Tribology in Metalworking, Friction, Lubrication and Wear", ASM, Metals Park, Ohio, USA, 1983
- [4] Schipper D.J., "Transition in the lubrication of concentrated contacts", Ph.D. thesis, Univ. of Twente, 1988
- [5] Haar R. ter, "Friction in Sheet Metal Forming, the influence of (local) contact conditions and deformation", Ph.D. thesis, Univ. of Twente, Enschede, 1996
- [6] Carleer B.D., J. Huétink, "Closing the Gap between the Workshop and Numerical Simul. in Sheet Metal Forming" *ECCOMAS'96 Proc.* p554-560, Wiley
- [7] Carleer B.D. "Finite element analysis of deep drawing", Ph.D. thesis, Univ. of Twente, Enschede, 1997
- [8] Wouters P., G. Montfort, J. Defourny, In: Recent developments in Sheet Metal Forming Technology, M.J.M. Barata Marques, Lisbon, 1994, p. 389-401
- [9] Carleer B.D., P.T. Vreede, M. Louwes, J. Huétink, Modelling Drawbeads with FEM and Verification, *J. Mat. Proc. Tech.*, **45/1-4**, 1994, p. 63-68

- [10]Carleer B.D., T. Meinders, J. Huétink, "Equivalent drawbead model in finite element simulations", *conference proc. Numisheet*, Detroit, 1996, p25-31
- [11]Vegter H., P.Drent, J.Huétink, "A planar isotropic yield crit. based on mech. testing at multi-axial states", *proc. Numiform '95 Balkema* p. 345-350
- [12]Huétink,J. P.T. Vreede and J. van der Lugt, 'Progress in mixed Eulerian-Lagrangian finite element simulation of forming processes', *Int. J. Num. Meth. Eng.* **30**, 1441-1457 (1990).
- [13]Liu,W.K. H. Chang, J.S. Chen and T. Belytschko, 'Arbitrary Lagrangian-Eulerian Petrov-Galerkin finite elements for nonlinear continua', *Comp. Meth. Appl. Mech. Eng.* **68**, 259-310 (1988).
- [14]Benson,D.J. 'An efficient, accurate, simple ALE method for nonlinear finite element programs', *Comp. Meth. Appl. Mech. Eng.* **72**, 305-350 (1989).
- [15]Benson,D.J. 'Vectorization techniques for explicit Arbitrary Lagrangian-Eulerian calculations', *Comp. Meth. Appl. Mech. Eng.* **96**, 303-328 (1992).
- [16]Baaijens,F.T.P. 'An U-ALE formulation of 3-D unsteady viscoelastic flow', *Int. J. Num. Meth. Eng.* **36**, 1115-1143 (1993).
- [17]Huétink,J.,P.N. van der Helm, 'On Euler-Lagrange Finite Element formulation in Forming and Fluid problems', *Proc. 4th Int. Conf. NUMIFORM*, 1992.
- [18]Leer,B.van, 'Towards the ultimate conservative differ. scheme V. A second-order sequel to Godunov's method', *J. Comp. Phys.* **32**, 101-136 (1979).
- [19]Hirsch,C. *Numerical computation of internal and external flows* **2**, John Wiley & Sons,
- [20]Helm,P.N.van der,J.Huétink,R.Akkerman, 'Comparis-on of Artificial Dissipation and Limited Flux in ALE FEM', *Int.J.Num.Meth.Eng.* **40**,1998
- [21]Brooks,A.N, T.J.R.Hughes,'Streamline upwind/Petr-ov-Galerkin formulations for convect. domin. flows', *Comp. Meth. Appl. Mech. Eng.* **32**, 199-259 (1982).
- [22]Donea,J. 'Arbitrary Lagrangian-Eulerian finite ele-ment methods' in *Comp. Meth. in Mech.* **1** ed. by T. Belytschko and T.J.R. Hughes, Elsevier, 1983.
- [23]Website <http://www.tm.wb.utwente.nl/home.htm>
- [24]Boogaard A.H. van den,H.H. Pijlman and J.Huetink. Anisotropic yield functions in a co-rotational reference frame, Esaform 2000 conference Stuttgart.
- [25]V. T. Meinders, Development s in numerical simulations of real live deep drawing process, PhD thesis University of Twente 2000
- [26]G. Kloosterman, An optimisation based contact algorithm, Esaform 2000 conference Stuttgart
- [27]A. Selman, T. Meinders, A.H. Van den Boogaard and J.Huetink. Wrinkling prediction with adaptive mesh refinement, Esaform 2000 conference Stuttgart