A Review of FEA Metal Forming Simulation Practices in Automotive Industry

C. Q. Hu

Contents

1. Factors affecting metal forming feasibility

Tooling (punch and die)

- Die face design (addendum)
- Kinematics: tipping, binder wrap, punch contact progression
- Draw beads design
- Die material (hardness, rigidity & friction behaviour)
- Blank location

Blank (sheet metal)

- Mechanical properties (r, n, r, YS, UTS values)
- Gauge (thickness)
- Variation of the mechanical properties and gauge
- Blank size
- Surface coating
- Surface finish (topography)
- Edge conditions
- Aging and pre-strain conditions

1. Factors affecting metal forming feasibility

Press

- Press type (hydraulic or mechanical)
- Binder pressure (force)
- Press speed

Lubrication

- Lubrication (type, viscosity, temperature and pressure sensitivity)
- quantity

Process noise

- Blank location
- Tool wear
- Dirt
- Ambient temperature and humidity
- Press counter balance pressure

2. Material models

An accuracy of FEA prediction is dependant on plastic models, in which different yielding criteria and hardening laws are suitable different materials and stamping process.

Yielding Criteria	Autoform		PamStamp 2G		Input requirements
	current	new	current	new	
Von Mises (isotropic)	yes	yes	yes	yes	$\sigma_{y,}$ r bar
Hill's 48 (Planar anisotropic)	yes	yes	yes	yes	σ_y, r values at 0, 45 and 90 degrees
Hill'90 (introducing bi-axial yield stress)	no	yes	yes	yes	σ_y, r values at more than three angles or σ_y at a bi-axial stress state
6 component Barlat	no	no	no	yes	Uni, bi-axial, and shear tests
Vegter	no	no	no	no	Uni, bi-axial, and shear tests

2. Material models

Hardening Laws :

Kinematic hardening, not isotropic hardening, takes account of non-linear strain path, such as bending/unbending, reverse drawing in a multi-stage forming process

Hardening law	Autoform		PamStamp 2G		Input requirements
	current	new	current	new	
Isotropic	yes	yes	yes	yes	$\sigma_{y,}$ UTS, n
Kinematic	no	no	yes	yes	$\sigma_{y,}$ UTS, n

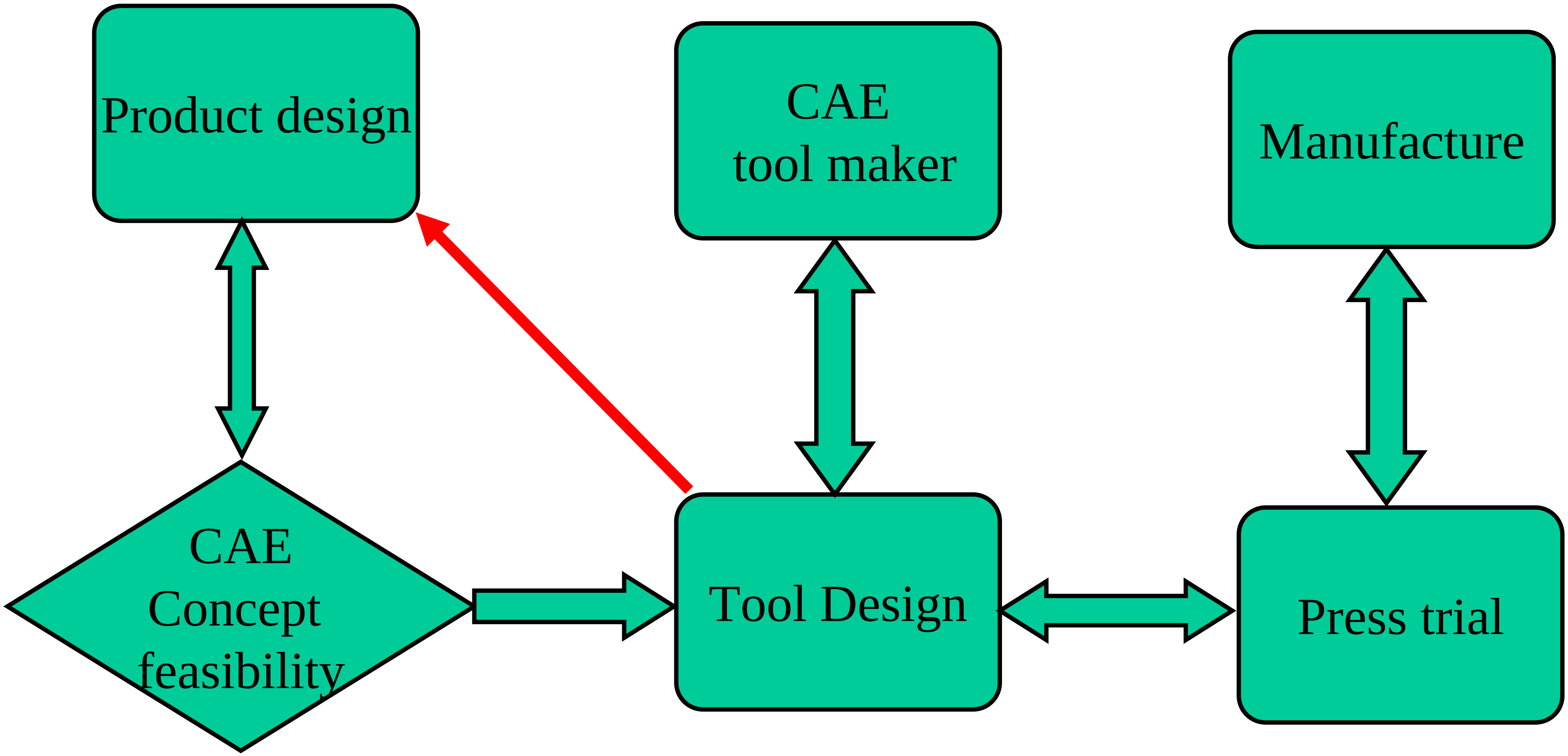
Hardening is represented by :

- A tensile test curve along the rolling direction
- The power law (Ludwik equation or Krupkowski equation) for steels
- The voce equation for Al alloys

3. Friction model

- In practice, coefficient of friction is dependant on contact pressure, slide speed (static and kinetic), blank coating, lubrication and tool surfaces, etc.
- Coulomb friction law, which assumes coefficient of fiction is constant regardless kinetic factor, contact pressure and slide speed, is the only option in both AutoForm and PamStamp 2G
- Other general FEA code, such as LS/Dyna, HKS/ABAQUS, provide more detailed friction models

4. Simulation methodology



4. Simulation methodology

4.1 Simulation practices in concept stage

AutoForm for most panels:

- To develop binder surface, addendum components
- To study feasibility, using:

  Von Mises (or Hill 45) yielding criterion, isotropic hardening law

  Blank holder load: decided using empirical formula,

  Coefficient of friction: 0.14(steel), 0.12 or 0.17 (Al)
- Using more conservative feasibility criteria

PamStamp 2G only for A panels (skin) for validation, using:

- Hill 45 yielding and isotropic hardening law
- Coefficient of friction: 0.14(steel), 0.12 or 0.17 (Al)
- Average mesh size : 10 mm, Adaptive mesh level, 2

4. Simulation methodology

4.2 Feasibility criteria in the concept stage

- For necking failure, allowing 20% safety margin
- For steel inner panels:

  Maximum thinning <25%

- For steel skin panels:

  Maximum thinning <25%, and minor strain≥1.0%, free of slid lines.

- For Aluminium skin panels:
- Maximum thinning <20%, and minor strain≥1.0%, free of slid lines.
- For wrinkling: using AutoForm default settings.

4. Simulation methodology

4.3 The simulation practices in the tool maker sector

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4.3 Feasibility criteria in the tool maker sector

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5. Parameters of current simulations and the sensitivity

5.1 Yielding criterion of Material model

Details

- For mild steels, Hill 48 appears to be accurate enough
- For HSS, Hill 90 is more accurate than Hill 48
- For Aluminium, Barlat's criterion is better than Hill 48 but need not only tensile tests but also bi-axial and shear tests.
- It has been claimed that Vegter criterion can describe yielding behaviour of HSS and Al alloys, and material tests is easier compared with that for Barlat model.
- More sophisticated and practical yield criteria for Al alloys has been expecting

5.2 Hardening law of Material model

- Isotropic hardening for linear strain path
- Kinematic hardening for nonlinear strain path

Details

5. Parameters of current simulations and the sensitivity

5.3 Material properties

- Thickness: wrinkling tendency, FLD_0, springback
- YS: material distribution, hardening exponent, springback
- UTS: (not a direct input parameter); hardening exponent, fracture strain
- n value: hardening, distribution of strain, FLD_0
- r values: deep draw ability
- Hardening curve: Krupkowski equation , Ludwik equation or converted tensile curve
- Blank orientation
- Direction of a tensile test for mechanical property input (0, 45, 90 degree)
- Forming limit curve (test methods)
- Blank mesh quality and adaptive mesh level

FLD_0

Hardening

n effects

5.4 Tools

- Tooling radius, size, punch type (flat or crown)
- The clearance between die and punch: material flow, wrinkling and springback
- Tool mesh design

Tool geo

5. Parameters of current simulations and the sensitivity

5.4 Process

- Blank holding pressure or load
- Press type (single or double action)
- Operation stages
- Artificial press speed setup including of type of curve and magnitude
- Boundary conditions, especially for springback prediction

5.5 Friction

- Using a constant coefficient of friction to quantify different coating of sheet steels and Al alloys, and other tribological factors

Example

5. Not included Parameters

5.1 Material properties

- Coating type (dipped and thickness or quantity
- Surface finish (topology)
- Material variation with a roll, or along the width of blank, especially for HSS
- Strain rate effect

5.2 Lubrication

- Type (Fluid-film, solid, Extreme Pressure (EP) lubricants)
- Quantity and distribution

5.3 Process

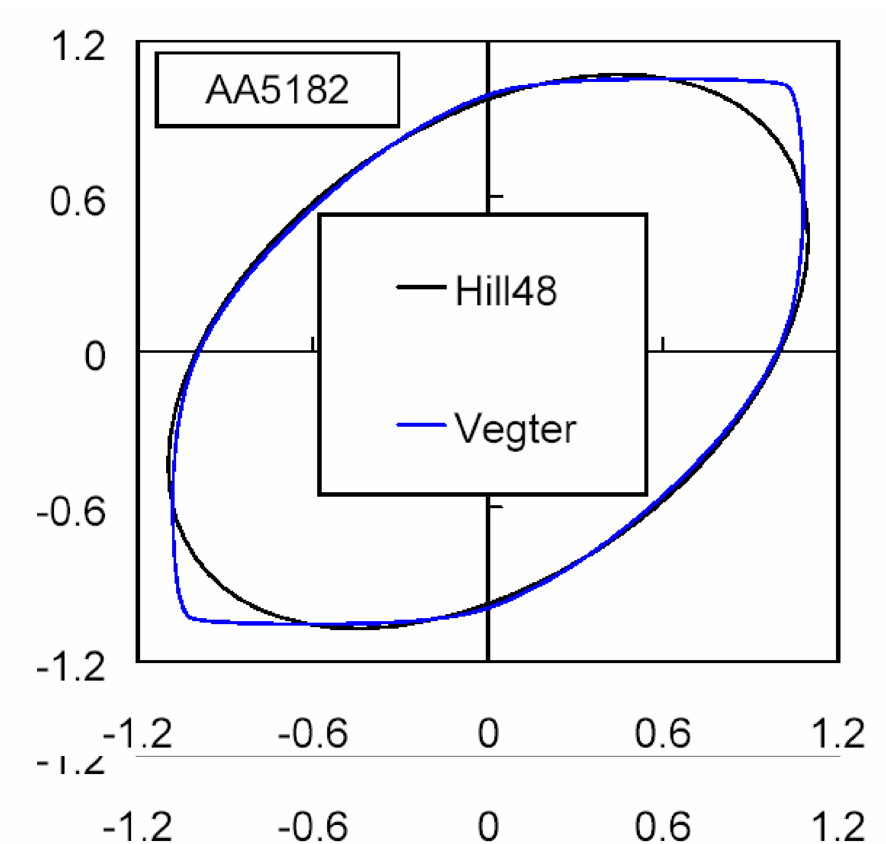
- Temperature

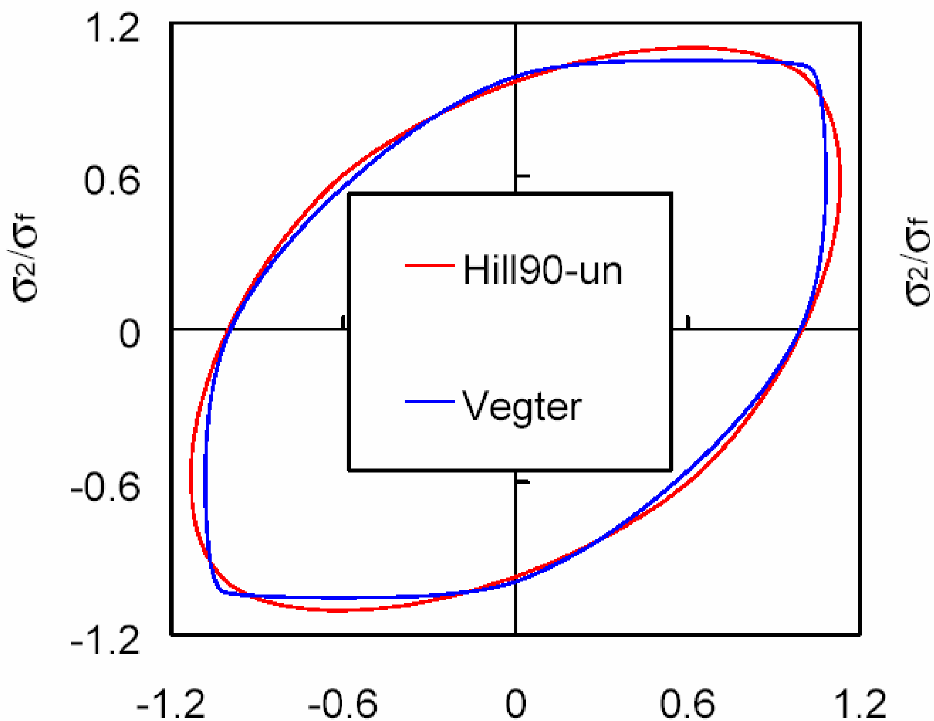
6. Summary

- FEA code and CAE experience have been developed to deal with for convention mild steel panels
- The accuracy of Wrinkling and springback prediction is considerablely dependant on model setup
- Regarding new materials, such as HSS and Al alloys, new material model should be investigated
- Due to confidential issues, the publication about bench mark test for commercial FEA codes is rare
- Simulation validation researches, dealing with new materials, different tool and complex forming process, is required

7. Appendix

7.1 Material models: Yielding criteria





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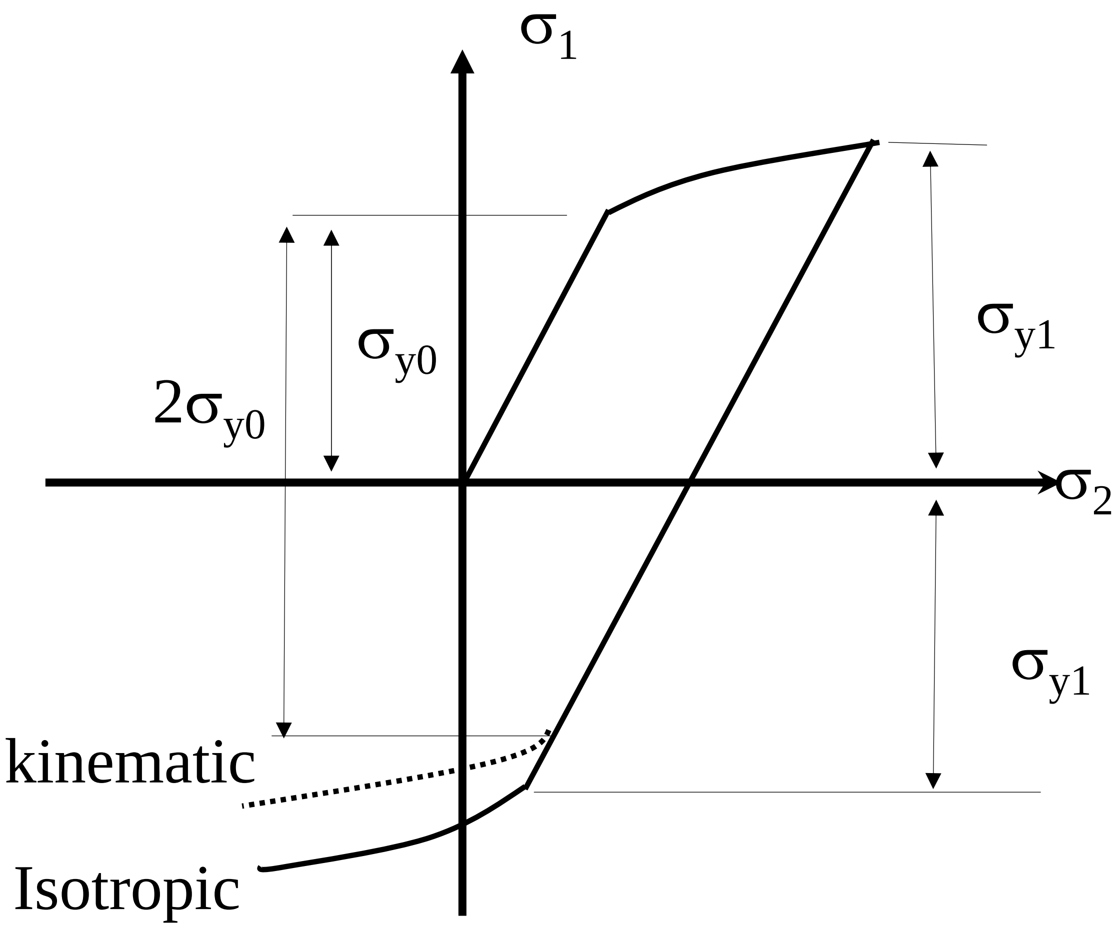
7. Appendix

7.2 Material models: hardening laws



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7. Appendix

7.3 Empirical formula: FLD_0=min(n/0.24, 1.0)*(23.0+14.6t)%

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7.4 Krupkowski equation: $\sigma=K^*(\varepsilon_0 + \varepsilon_p)^n$, and $K=UTS^*(e/n)^n$

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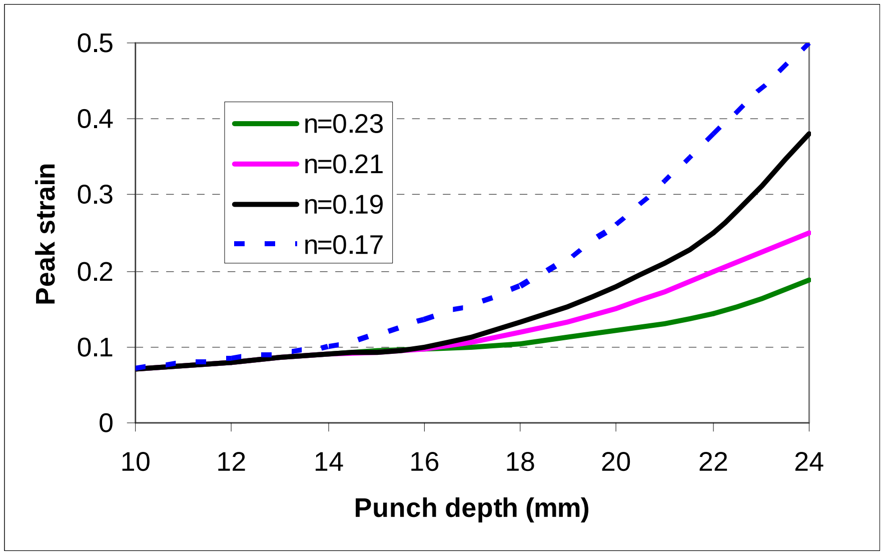
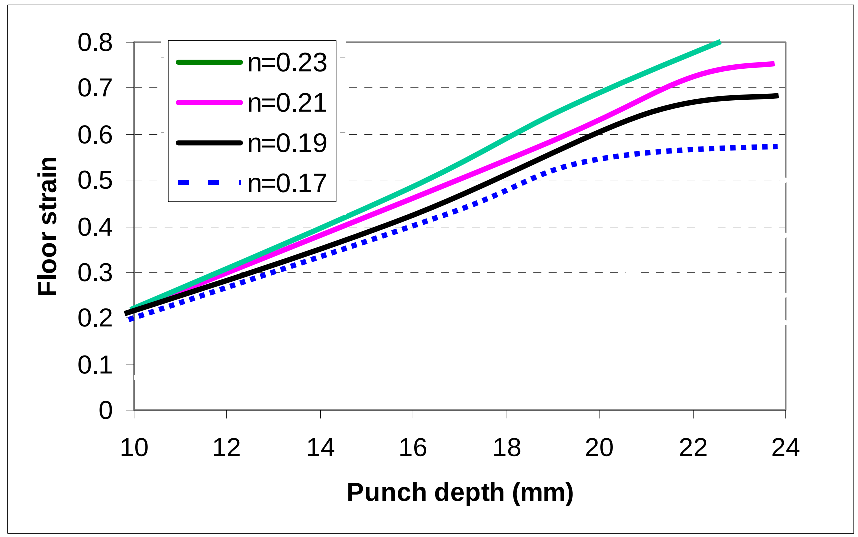
7.5 n effects on strain value





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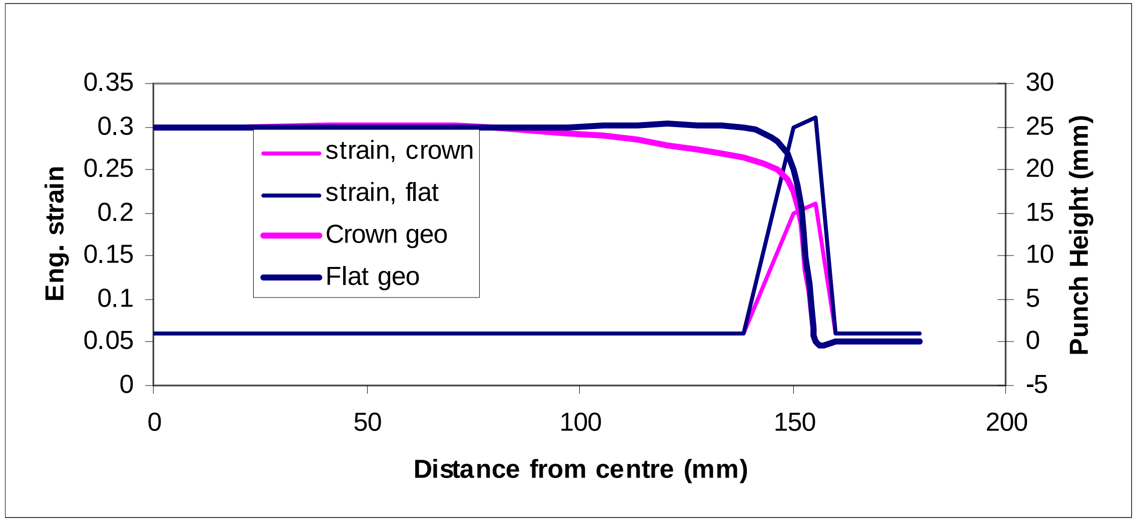
7.6 Tool geometry effects



7.6 Friction effects