Finite element analysis of multi-pass drawing under back tension using a virtual state-variable body-force method

MinCheol Kim¹), SeongWon Lee¹), JaeGun Eom²), ManSoo Joun³)

1) School of Mechanical Engineering, Gyeongsang National University(GNU), Jinju / Korea
2) TIC of Gyeongsang National University, Sacheon / Korea
3) Corresponding author, School of Mechanical Engineering / Engineering Research Institute, Gyeongsang National University/, Jinju / Korea, msjoun@gnu.ac.kr.
Applicability – Applications of the year 2009
Accuracy – Tensile test

Engineering strain (mm/mm)
Engineering stress (MPa)

Experiment (SCM435)
Analysis (SCM435)
Experiment (ESW95)
Analysis (ESW95)
Experiment (ESW105)
Analysis (ESW105)
Accuracy - Fracture prediction in tensile test
Accuracy - Extrusion test

SCM435

Contacted

ESW105

Non-contacted
Accuracy – Hot forging, bearing race

Internal crack

Damage

Metal flow and temperature

Accuracy - Cold forging, automobile part
Accuracy – Cold forging, rotor pole

Accuracy – Enclosed die forging, bevel gear

Enclosed die forging
KSPE Fall 2007
Accuracy - Hammer forging, ship engine part
Research background - Tube extrusion/drawing process

Simulation failures (2009)

Ours (2009)
Previous studies on central bursting defects

**EXPERIMENTS**

- Extrusion
- Drawing

\[
 r = \frac{r_c}{r_o} \times 100
\]

- \( r = 81 \)
- \( r = 90 \)
- \( r = 78 \)
- \( r = 84 \)
- \( r_{\text{mean}} = 83 \)

**PREDICTIONS**

- C. Soyarslan et al.
  - ABAQUS/ Explicit
  - Elasto-plastic
  - \( r = 72 \)

- K. Saanouni et al.
  - Forge
  - Elasto-plastic
  - \( r = 50 \)

- Labergeere et al.
  - ABAQUS/ Explicit
  - Thermoelasto-viscoplastic
  - \( r = 67 \)

- F. Ahmadi et al.
  - Rigid-plastic
  - \( r = 55 \)

- McAllen et al.
  - ABAQUS
  - \( r = 60.0 \)

- H. Cho et al.
  - DEFORM
  - \( r = 38 \)
Chevron crack predictions

(a) Case 1

(b) Case 2

(c) Case 3

(d) Case 4

\[ r_{mean} = 82 \]
Effect of back tension – Central bursting defect

R = 0%

R = 10%

R = 20%
Swaging analysis – Motion of pusher

- Experiments
- Modelling
- Predictions with rigid mount
- Predictions with elastic mount
Artificial body force method

\[ \sigma_{ij,j} = -f_i = -f_i^A + f_i^R \]
Test Ex. 1 - Drawing process with back tension exerted

- Flow stress
  \[ \bar{\sigma} = 72.7 \varepsilon^{0.22} \text{MPa} \]

- Coefficient of Coulomb friction
  \[ \mu = 0.05 \]

- Die velocity
  \[ v = -1.0 \text{mm/s} \]

- Body force
  \[ 9.8912 \text{N/mm}^3 \]

- Resultant force
  \[ 1422 \text{N} \]

- Artificial body force

- Non-separable die

- Temperature range:
  - 20°C to 3000°C
Test Ex. 1 - Predictions

- **Effective strain**
- **Effective stress**

**Metal flows and dimensions**

- Puller die:
  - 3.0mm
  - 2.54mm

- Dimensions:
  - 0.08
  - 0.35
  - 0.40
  - 200
  - 600
  - 800
  - 50
  - 25
  - 50
  - 100
  - 400
  - 0.08
  - 0.35
  - 0.40
  - 0.45
  - 0.35
  - 0.40
Tube extrusion and drawing process with back pressing

Back pressing force 1422N

(a) Extrusion  (b) Drawing  (c) Drawing
Test Ex. 2 - Tube extrusion and drawing process

Input backpressing force = 1422 N

First stage

Second stage

Third stage

KSTP 2009
Application Ex. 1 – Six-pass rod drawing

◎ Process information

Artificial body-force specified region

<table>
<thead>
<tr>
<th>Dimension \ pass</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_i$ [mm]</td>
<td>7.00</td>
<td>6.64</td>
<td>6.30</td>
<td>5.98</td>
<td>5.67</td>
<td>5.38</td>
</tr>
<tr>
<td>$r_o$ [mm]</td>
<td>6.64</td>
<td>6.30</td>
<td>5.98</td>
<td>5.67</td>
<td>5.38</td>
<td>5.10</td>
</tr>
<tr>
<td>$l$ [mm]</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>$\alpha$ [°]</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>
Material information
- SWCH10A
  - $\sigma_Y \approx 295$ MPa

Friction
- Coefficient of Coulomb friction: 0.02

Back tensile stress
- $R = 0\%$ (Case 1)
- $R = 10\%$ (Case 2)
- $R = 20\%$ (Case 3) of $\sigma_Y$

Flow stress

![Graph showing flow stress and true stress vs. true strain]
Application Ex. 1 – Predictions

For Case 2

Strain Damage
Strain Damage
Strain Damage
Strain Damage
Strain Damage
Strain Damage

Pass 1
Pass 2
Pass 3
Pass 4
Pass 5
Pass 6
Effect of back tension – strain and damage

- Back tensile stress = Initial yield stress multiplied by R
Effect of back tension – strain and damage

Back tensile stress = Initial yield stress multiplied by R
Effect of back tension – Drawing force

![Graph showing the effect of back tension on drawing force.](image)

<table>
<thead>
<tr>
<th>Pass</th>
<th>R = 10%</th>
<th>R = 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.4</td>
<td>8.8</td>
</tr>
<tr>
<td>2</td>
<td>4.0</td>
<td>7.9</td>
</tr>
<tr>
<td>3</td>
<td>3.6</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>3.2</td>
<td>6.4</td>
</tr>
<tr>
<td>5</td>
<td>2.9</td>
<td>5.8</td>
</tr>
<tr>
<td>6</td>
<td>2.6</td>
<td>5.2</td>
</tr>
</tbody>
</table>
Effect of back tension – Die pressure

$\sigma_{yy} = 0 \text{ MPa}$

$\sigma_{yy} = 29 \text{ MPa}$

$\sigma_{yy} = 58 \text{ MPa}$

$\bar{\sigma} = 400 \text{ MPa}$

$P = 8800 \text{ N}$

$P = 12700 \text{ N}$

$P = 16500 \text{ N}$
Effect of back tension – Central bursting defect

R = 0%

R = 10%

R = 20%
A twenty-pass wiredrawing process was simulated in a fully automatic manner by the presented approach.

- Radius of initial material is 7mm,
- Reduction of area per each pass is all 10%.
- Die land length is 2.0 mm.
- All die conical angles are 10°.

Simulation information

- Flow stress: The same with Ex. 1
- Coefficient of Coulomb friction: \( \mu = 0.02 \)
- Body force: 0%, 20%
Variation of effective strain and damage

For the 20% back tension case

(a) Pass 11  (b) Pass 14  (c) Pass 17  (d) Pass 20
0% back tension vs. 20% back tension
Artificial state-variable body-force method was presented to deal with back tension or compression during drawing with higher accuracy and generality.

- Some appropriate region of the material was considered as body-force prescribed domain where the body-force was defined by a function of an artificial state variable.

- The artificial state-variable was treated as one of state variables in remeshing with the result that the domain can be maintained during remeshing, which increases the generality of the approach.

The approach was successfully applied to fully automatic simulation of two application examples including a six-pass rod drawing process and a twenty-pass wiredrawing process.

- With the presented approach, the predictions with higher accuracy could be obtained in terms of effect of back tension or compression.

- Generality of the approach is also noteworthy.
Research background – Forging defects

- Hot shortness
- Metal flow
- Buckling
- Air-trapping
- Folding
- Under-filling
- Piping
- Bad spheroidizing
- Chevron crack
- Shape defect
- Ductile fracture