Study of flow balance over a press cycle with HyperXtrude

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Abstract: In this work, flow balance in extrusion of aluminum has been studied. The aim of the study is to find how process parameters influence extrusion flow balance. This is done by investigating the influence of billet taper, billet temperature and ram speed on the relative run-out velocity from two separate cavities. The finite elements software used in this study is Altair HyperXtrude.
Outline

- Motivation
- FEM Modeling
- Process parameters
- Design of experiments
- Some results
- General linear model
- Conclusion
- References
Motivation

- Important properties of extruded aluminium sections are:
  - Shape
  - Mechanical properties
- These are influenced by
  - Flow balance
  - Temperature distribution
- Failure to meet specifications of shape and mechanical properties will result in reduced material recovery or customer claims.
FEM model sketch

2D axisymmetric

Ram force

outer profile

inner profile
FEM model, axisymmetric

- Symmetry boundary condition on both sides of section
- Heat fluxes representing thermal interaction with die, container and ram all around the model
- Full sticking friction inside the container and on bearings
- ~ 11000 elements
- 10 elements through thickness of profile
- 4 elements in radial direction, along the 10° section
- Smaller element size near surfaces
Design of experiments

- Analysis of variance (ANOVA)
- 3 parameters
  - Ram speed: 10, 20, 30 (mm/s)
  - Axial billet Taper: 10, 40, 70 (°C/m)
  - Front billet Temperature: 450, 480, 510 (°C)
- 27 combinations.
- Two responses:
  - Standard deviation of $\frac{V_i}{V_o}$
  - Standard deviation of $\frac{T_i}{T_o}$
Results

Temperature

Velocity
Results, examples

Velocity

Temperature
General Linear Model

- GLM is used to perform analysis of variance and regression analysis.
- For each of the cases, we calculate standard deviations:
  - of the exit speed ratio throughout the press stroke
  - of the temperature ratio throughout the press stroke
- The standard deviation:
  - has a small value if the ratio is near constant (favorable).
  - has a large value if the ratio changes significantly.
GLM results

\[ \sigma (V) = 0.0325 + 0.000327 \text{ Ram (mm/s)} - 0.000052 \text{ Temp (C)} + 0.000246 \text{ Taper (C/m)} \]
\[ \text{R-Sq} = 97.7\% \]

\[ \sigma (T) = 0.00453 + 0.000105 \text{ Ram (mm/s)} - 0.000010 \text{ Temp (C)} + 0.000043 \text{ Taper (C/m)} \]
\[ \text{R-Sq} = 94.3\% \]
Conclusion

- High values of ram speed and taper give high values of the standard deviation.
- Increasing the front billet temperature gives a reduction of the standard deviation.
- It is not desirable to reduce the ram speed much, since this means loss of productivity.
- Therefore a high front billet temperature and low taper are recommended in practice in order to achieve the best possible flow balance and stability of shape.
Further applications

- Running the model with multiple press cycles.
- Including die and container with heat exchange evolution.
- Running full 3D models to study temperature, and effect of container heating and cooling.
References

- Sigurd Støren, Per Thomas Moe, Ch. 8 of Handbook of Aluminum: Vol. 1: Physical Metallurgy and Processes
- Douglas C. Montgomery, Design and Analysis of experiments
- HyperXtrude user’s manual, Altair HyperWorks.
- MiniTAB user’s manual.