Finite Element Analysis of a Plate Forging Considering Air Pocketing Phenomena

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Application of CAE to bearing parts manufacturing

Forging

- By AFDEX
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- Forging

- Internal crack

- Damage

- Metal flow and temperature
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Ring rolling

- Cage
- Ball bearing race

- Taper roller bearing race
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Rotary forming

- A hub bearing unit

- A defect

- Predictions

- Comparison between experiments and predictions
Contents

- Research backgrounds
- Description of the problem
- Methodology of predicting the problem
- Applications
- Conclusion
Research backgrounds

Air pocketing

- Enclosed spaces constructed by material and dies or tools appear in metal forming.
- These enclosed spaces involve a mixture of oil, lubricant, air, and even unidentifiable impurities.
- The air pocketing can cause under-filling or surface defects of the products.

Literature survey

Conceptual drawing of air pocketing phenomena
Mathematical model of air pocketing phenomena

\[ \Delta \tilde{e}_v^j = \int_{V_j}^{V_j + \Delta V_j} \frac{dV}{V} = \ln(1 + \frac{\Delta V_j}{V_j}) \]  

\[ \tilde{e}_v^j = \tilde{e}_v^{j-1} - \Delta \tilde{e}_v^j \]

\[ p_{air} = \begin{cases} 
B \tilde{e}_v^j & \text{when } B \tilde{e}_v^j < p_{mp} \\
 p_{mp} & \text{when } B \tilde{e}_v^j \geq p_{mp}
\end{cases} \]

The algorithm for calculating

\[ B \tilde{e}_v^j < p_{mp} \quad (1) \]

\[ B \tilde{e}_v^j \geq p_{mp} \quad (2) \]

\[ p_{mp} = \text{Min}(p_{local}^1, p_{local}^2, \ldots) \]

\[ p^1, p^2 = \text{Maximum pressure at the neighboring die-material interface of the air pocket} \]
Application example – Cold plate forging of a bearing part

Process design of the application example

Simulation information of the process

○ Flow stress:
\[ \bar{\sigma} = 580.0(1.0 + \bar{\varepsilon} / 0.024) \text{MPa} \]

○ Friction law:
- Law of Coulomb friction
- Coefficient of Coulomb friction: \( \mu = 0.05 \)

○ Type and number of elements:
- Quadrilateral element
- 2000

○ Bulk modulus of elasticity:
\[ B = 500 \text{ MPa} \]
Predictions with experiments – Stage 1

- Without air pocket considered

- With air pocket considered
Predictions with experiments – Stage 2

- Without air pocket considered
- With air pocket considered
Pressure variation inside the air pocket — Stage 2

[Diagram showing pressures at different locations labeled A and B with values 637, 1423, 730, 820, 1321, 1558.]

[Graph showing time vs. air pressure with stages 2(A) and 2(B) indicated.]
Predictions with experiments – Stage 3

- Without air pocket considered
- With air pocket considered
Pressure variation inside the air pocket – Stage 3

[A diagram showing the pressure variation at different points labeled A, B, C, and D.]

[Graph showing the air pressure over time for Stage 3(A), Stage 3(B), Stage 3(C), and Stage 3(D).]
Application to a hot forging process

- Process design of the application example
- Simulation information of the process

○ Flow stress:
  \[ \bar{\sigma} = 51.8 \dot{\varepsilon}^{0.178} \text{MPa} \]

○ Friction law:
  - Law of Coulomb friction
  - Coefficient of Coulomb friction: \( \mu = 0.2 \)

○ Type and number of elements:
  - Quadrilateral element
  - 2000

Stage 1

Stage 2

Stage 3
Predictions - Stage 2

- Without air pocket considered
- With air pocket considered
Predictions — Stage 3

- Without air pocket considered
- With air pocket considered
Predictions—Stage 3

Without air pocket considered

With air pocket considered
Conclusions

- A new finite element approach to simulating metal-forming processes considering air-pocketing phenomena was presented.

- The approach was used to simulate a plate-forging process to analyze under-filling defects near the die corners.

  - The internal pressure of an air pocket was assumed to be a linear function of the volumetric compression ratio of the air pocket when it was less than the maximum die normal stress of the neighboring contact interfaces of the air pocket. When it exceeded the minimum peak die normal stress of the neighboring contact interfaces, the accumulated volumetric compression ratio was purposely lowered to make the internal pressure identical to the minimum peak die normal pressure of the neighboring contact interfaces.

- The validity of the results was verified by comparison of predictions with the experiments.