Intelligent Metal Forming Simulation Technology and Its Applications

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Why Is Intelligent Simulation Important?

- **Metal forming simulation is inherently difficult**
  - Creativeness of metal forming process design
  - Multi-stage and compound processes

- **CAE application is diffusing widely to small or midsized companies**
  - Many users are not proficient at the related theories or don’t have sufficient process design experience

- **Chronic problems**
  - Many engineers still think the usage is difficult
  - Many users still consider the predicted results as just one of references and don’t try to obtain more accurate solutions because of the lack of confidence in the solution accuracy.

- **Ways to solve the problems**
  - Intelligent metal forming simulation
Requirements for Intelligent Forging Simulation

○ Solution accuracy
  - Tensile test simulation
  - Minimum volume loss or change
  - Accurate solution for well defined defect formation problems

○ Intelligent remeshing
  - Adaptive remeshing capability
  - Minimized difference in BVP between before and after remeshings
  - Maintenance of characteristic boundary or surface with sharp edges
  - Configuration-friendly mesh system
  - Minimized smoothing of state variables
  - Robustness of remeshing

○ Easy-to-use pre/post processor
  - Many intelligent capabilities or fool proof functions
  - Automatic calculation of coefficients related to the theories
  - Easy to learn
  - Fully automatic simulation of multi-stage metal forming processes
  - 2D/3D or hot/cold combined simulation

○ Applicability to solve problems of industrial metal forming processes
  - All kinds of bulk metal forming processes can be simulated by AFDEX
  - Applicability to new creative metal forming processes
Introduction to AFDEX, an Intelligent MFS

Key Features

- Rigid-Thermoviscoplastic FEM with Intelligent Remeshing
- Many Easy-to-Learn or Fool-Proof Functions
- Many User Friendly Capabilities and CAD I/F
- Fully Automatic Simulation of Multi-Stage Processes

Coupled Analysis in Forging

Flow analysis of workpiece

Heat transfer analysis of workpiece

Heat transfer analysis of die set

Die Set Structural Analysis

Die insert
- Elastoplastic analysis

Shrink ring
- Elastic analysis

Other tools
- Elastic analysis
- Contact load

- Heat generation
- Flow stress change
- Mechanical load
- Die geometry change
- Heat transfer
- Thermal load

2D: Quadrilateral

3D: Tetrahedral/Hexahedral
Accuracy – Tensile test

Engineering strain (mm/mm)
Engineering stress (MPa)
0 0.1 0.2 0.3 0.4
200
400
600
800
1000
1200

Experiment (SCM435)
Analysis (SCM435)
Experiment (ESW95)
Analysis (ESW95)
Experiment (ESW105)
Analysis (ESW105)
Accuracy – Compression test, Extrusion test

![Graph showing True Stress vs True Strain for SCM435 and ESW105]
Accuracy – Hot forging, bearing race

Accuracy – Cold forging, automobile part
Accuracy – Hammer forging, ship engine part
Accuracy – Ring rolling, hot, cold, bearing races

Hot ring rolling

Cold profile ring rolling

Accuracy – Cold forging, rotor pole

Accuracy – Enclosed die forging, bevel gear
Solution Delicateness – Quadrilateral elements

Solution Delicateness – Tetrahedral elements

Generated mesh

Desired mesh density

Comparison with DEFORM – Gear carrier

DEFORM 3D, 2005

Jie Wan et al., 2005
Engineering with Computers
Vol. 21

AFDEX3D, 2007
Solution Delicateness – Specially constructed mesh
Solution Delicateness – Characteristic boundary
Comparison with DEFORM – German bearing part

AFDEX 3D

DEFORM 3D

AFDEX (e_min)
AFDEX (e_max)
DEFORM (e_min)
DEFORM (e_max)

Step number
Effective strain

$0 \, \, 20 \, \, 40 \, \, 60 \, \, 80 \, \, 100 \, \, 120$

$10^0 \, \, 10^1 \, \, 10^2 \, \, 10^3 \, \, 10^4 \, \, 10^5$
Solution Delicateness – Robustness
Five-stage automatic cold forging sequence

1st stage

2nd stage

3rd stage

4th stage

2D

3D

User-Friendliness – 2D, detailed metal flow lines

Precision simulation of metal flows

Metal flow lines for design

Old

0.91kg

0.82kg

New

Int. J. Maxh. Tools Manuf. 1998
User-Friendliness – 3D, detailed metal flow lines
User-Friendliness – User space, material DB
User-Friendliness – Powerful Pre/Post processor
Applicability – Examples applied while being developed
Applicability – Fracture prediction in tensile test

Elongation [mm]
Tensile load [kN]

Experiment
Prediction

Fracture prediction in tensile test
**Applicability – Enclosed die forging**

- Bevel gear
- Inner race
- Tripod
- Long shaft bevel gear

Enclosed die forging
Applicability – Roll forging

EFFECTIVE STRAIN
TIME: 2.00E-07 sec
UNIT:
Applicability – Ring rolling

- Cold profile ring rolling
- Wind tower flange ring rolling
- Hot profile ring rolling
Applicability – Radial forging

Train axle shaft

Pass 1

Pass 2

Pass 3

Round rod radial forging

Train axle shaft
Applicability – Roll piercing
Applicability – Swaging
Applicability – Axial ring forging
Applicability – Radial ring forging
Applicability – Tube drawing with backpressing

First stage

Second stage

Third stage

Input backpressing force=1422 N

KSTP 2009
Comparison with DEFORM – Pipe drawing

Process: Pipe drawing with backpressing

AFDEX 2D (2009)

DEFORM 2D (2009)
Applicability – Cross wedge rolling
Applicability – Chevron defect in extrusion

- $\alpha = 30^\circ$
- R.A. = 18
- $\mu = 0.03$

- $\alpha = 30^\circ$
- R.A. = 30
- $\mu = 0.03$

KSPT 2010
Comparison with FORGE – Chevron crack

AFDEX, 2010

FORGE, 2004
Applicability – Pore closing

Cogging

Cylinder compression, upsetting
Applicability – Cold plate forming
Applicability – hot plate forming
Applicability – Sheet metal forming

- punch
- binder
- workpiece
- die

Distance from center (mm)
Thickness strain
0 20 40 60 80
-0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2

Experiment
Solid-shell (Xu et al.)
Tetrahedral, Single-layer
Tetrahedral, Double-layer

Applicability – Sheet metal forming

- punch
- binder
- workpiece
- die

Distance from center (mm)
Thickness strain
0 20 40 60 80
-0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2
Applicability – Superplastic sheet metal forming
Applicability – Structural analysis, die with shrink fit
Applicability – 3D die structural analysis

[Diagram showing 3D structural analysis with effective stress levels for SCM435 and ESW125 materials.]

- **SCM435**
  - Effective stress: 3400 MPa
  - Max: 913 MPa
  - Min: 0 MPa

- **ESW125**
  - Effective stress: 4000 MPa
  - Max: 913 MPa
  - Min: 0 MPa

[Color scale indicating stress levels with units in MPa.]
Conclusions

⊙ Requirements for intelligent metal forming simulation (IMFS)
  - Optimized and adaptive mesh generation techniques play key role at IMFS.
  - Solution accuracy should be verified.
  - Easy-to-use pre/post processors.
  - Applicability for all kinds of metal forming processes.

⊙ AFDEX is an intelligent metal forming simulator
  - Intelligent meshing and remeshing capabilities.
  - Generalized metal forming simulator.
  - The most easy-to-use pre/post processors.
  - The most accurate solution.
  - Proven applicability.
Applicability – Applications of the year 2009