Simulation and Optimization of Metal Forming Processes

New Applications and Challenges


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Outline

• Need for Process Simulation in Metal Forming.

• Requirements for Process Simulation.
  – Material Properties.
  – Interface Friction Conditions.

• Selected Process Modeling Case Studies.
  – Precision Cold, Warm and Hot Forging.
  – Stamping.

• Summary and Concluding Remarks.
Improvement of Profitability

Steps to increase profitability in global competition:

– Increase material utilization (reduction of scrap, flash, etc.).
– Reduce defects and scrap rate.
– Increase die service life.
– Increase utilization rate of forming equipment.
– Process optimization by use of computer aided engineering (CAE) tools.
– Increase automation and decrease labor content.
– Efficient information management.
– Training of personnel/access to advanced technology.
Main Goal: Reduce part development time and cost, and increase quality and productivity.

Specific Goals:

– Optimization of blank-holder force and blank geometry in stamping.

– Optimization of internal pressure vs. axial feed in tube hydroforming.

– Preform and die design optimization for improved material yield in hot forging.

– Die material selection and process design for improved die life in warm and hot forging.

– Prediction of internal defects and part quality in cold forging.
Forging: Cylinder Compression Test

- Barreling occurs at the center plane of the specimen due to the friction at the die-specimen interface.

- Upset load versus stroke and shape of the billet at the end of forming are used in FE simulation-based inverse analysis technique to estimate the flow stress that compensates for friction.

(Cho et al, 2003)
Stamping and Sheet Hydroforming: Viscous Pressure Bulge (VPB) Test

- Material properties obtained from tensile test are not adequate for process simulation.
  - Stress conditions in stamping/sheet hydroforming are often biaxial compared to uniaxial in the tensile test, and
  - The maximum effective strain achievable in the tensile test is relatively small because of local necking.

(Gutscher et al, 2004)
Surface Properties: Indentation Test

- The indentation (micro-hardness) test is used to estimate local flow stress of the material near the surface.

- The load versus stroke is measured continuously and used as an input to an FE simulation-based inverse analysis technique to estimate the flow stress.
Process Modeling Requirements

-Interface Friction Conditions in Forging-

Forging: Ring Compression Test (RCT) and Double Cup Extrusion Test (DCET)

• The DCET is used to evaluate lubricants in processes that involve high contact pressures and surface expansion. Lubricants are evaluated and ranked on the basis of the cup height ratio.

• The RCT is mainly used to test lubricants in cold heading and warm/hot forging due to its simplicity. Lubricants are evaluated and ranked on the basis of the change in ring inner diameter for different height reductions.

• The friction factor in both cases is estimated using calibration curves developed through FE analysis.
Process Modeling Requirements
-Interface Friction Conditions in Forging-

a) Double Cup Extrusion Test.  b) Ring Compression Test.
Stamping: Deep Drawing Test

- This test emulates the interface condition that exists in production, both in the flange and in the punch.

- Circular cups are drawn from a blank of fixed draw ratio but with different blank holder force until they fracture. The largest blank holder force that can be used to draw the cup without failure indicates the performance of the lubricant.

- The higher is the blank holder force, the better is the performance of the lubricant in the test. Also, a large punch force indicates bad performance of the lubricant.
Process Modeling Requirements
-Interface Friction Conditions in Stamping-

Stamping: Deep Drawing Test

• Experimental evaluation of lubricant performance.

(Kim et al, 2006)
Orbital Forming of Wheel Bearing Assembly:

Determine the influence of various process parameters such as axial feed, tool axis angle, etc., on the residual stress in the bearing inner race of the assembly, deformed geometry of the spindle, and the axial load that the assembly can withstand.

(Cho et al, 2004)
Microforming of a Surgical Blade:

- Using FEA with die stress analysis, the flash thickness was reduced such that grinding of flash was replaced by electro-chemical machining (ECM).

- The designed tool geometry was successfully used in production to coin this part.

Initial blank (Blank thickness = 0.1 mm; Final blade thickness = 0.01 mm)

Formed part

(Palaniswamy et al, 2002)
Hot Forging of Suspension Components:

- A study was conducted for a tier one aluminum forging supplier to optimize the preform and die (blocker and finisher) designs, forging temperatures as well as flash dimensions.
Material yield was increased by ≈15% through preform optimization, with an additional 3-4% improvement through blocker die design.
Die Wear Study (Forging Industry Association):

• Main Goal: Prediction and improvement of die life in warm and hot forging processes through combination of FEA and shop-floor trials under production conditions.

• Specific Goals:
  – Identification of interface conditions at start-up and steady-state.
  – Selection and comparison of die materials through FEA.
  – Design of shrink-fitted dies with ceramic and carbide inserts accounting for thermal expansion during preheating and forging.
  – Preform and die design for reduction of die-workpiece contact time and relative sliding.
Forging Process Simulation with Production Cycle-time Data:

- Die chill time i.e. the time spent by the billet on the bottom die until contact with the top die.

- Deformation or forging time i.e. the time from start of deformation until bottom dead center (BDC).

- Dwell time i.e. the time until part removal/ejection.

- Cooling time i.e. the lubrication spray time and the dwell time until the next billet is placed on the die.
Process Modeling Applications

-Improvement of Die Life in Forging-

• Scrap rates were reduced by 50% in a hot forging process through improved preform design and die material selection developed by FEA of the forging process (Impact Forge, USA).

• Effect of die material properties on thermal fatigue performance was investigated in order to screen alternative die materials.

• Loss of compressive stress in a shrink-fit die was determined through simulation of die heating and multiple-cycle forging (American Axle, USA).

• The application of matrix-high speed steels is being explored through production trials (Hirschvogel, USA).
Determination of Slot Location and Shape:

- FEA using PAMSTAMP-2000™ was used to determine the optimal slot shape and location in the initial blank for a sample part (automatic transmission component).

- This helped to eliminate an expensive post-stamping laser cutting operation.

(Palaniswamy et al, 2002)
Programming a Multipoint Cushion System:

- As part of a USCAR project, an optimization technique was developed coupled with FE codes to estimate the blank holder force that is variable in space and constant in stroke.

- The developed software was used to predict the blank holder force required to form a full size automotive panel (Lift-gate – inner) from three different materials (aluminum alloy A6111-T4, t=1.0 mm, BH210, t=0.8 mm and DP500 t=0.8 mm).

(Palaniswamy et al, 2002)
Process Modeling Applications

-Blank-holder Force Control-

A6111-T4, $t = 1 \text{ mm}$

DP500, $t=0.8 \text{ mm}$

BH210, $t=0.8 \text{ mm}$
A process sequence was designed for the part shown. The existing design was improved through FE simulation to reduce the potential for failure in the formed part (excessive thinning and wrinkling).
Warm sheet forming of magnesium and aluminum alloys

- A study was conducted, in co-operation with Aida-America, to investigate deep drawing of a magnesium alloy, an aluminum alloy and austenitic stainless steel at elevated temperature.

- The sheet was heated in the tooling and then formed at different speeds using a servo motor driven press that allows infinite degrees of freedom to control the ram motion and speed.

- Maximum draw ratio of 3.0 can be obtained at 300° C with maximum ram velocities of 2 mm/sec and 5 mm/sec for AZ31B and AL5754-O sheet material, respectively.
Process Modeling Applications
-Warm Forming of Lightweight Alloys-

Magnesium: AZ31B
Aluminum: 5754-O

Limiting Draw Ratio (LDR)
Forming velocity [mm/s]

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Summary

• Process modeling through FE simulation is an essential tool in modern metal forming to reduce the development cost and time.

• Continuous development of FE software for metal forming has increased its scope to cover a large range of metal forming processes including warm sheet forming and metal cutting.

• In this paper an overview is given on the application of FE simulation for industrially relevant practical problems.
References


