Evaluation of MSC.SuperForge for 3D Simulation of Streamlined and Shear Extrusion Dies

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ABSTRACT

The main objective of this study is twofold: (1) to evaluate a new 3-D metal forming simulation package by comparing its simulation results with the simulation results of a validated package for the same process, and (2) to optimize the feeder plate design for an extrusion die process using 3-D metal forming simulation.

A new metal forming simulation package, MSC.SuperForge, has been recently introduced commercially. This package uses a finite-volume analysis method, which is fundamentally different than the finite-element analysis method used by most of the other commercial metal forming simulation packages.

A primary objective of this study is to evaluate MSC.SuperForge by comparing its simulation results with the simulation results of DEFORM™-3D, a validated finite-element based forging simulation package. A 3D extrusion process using a streamlined die design was selected for the evaluation, since this process produces a relatively complex I-section extruded shape.

A secondary objective of the study is to investigate shear extrusion dies in 3D extrusion processes with MSC.SuperForge. Although streamlined extrusion dies are generally preferred over sharp corner shear dies for extrusion because streamlined dies produce lower extrusion loads and more uniform material flow, streamlined extrusion dies are more difficult to design and more expensive to manufacture than shear dies. Until this current study, however, few attempts have been made to analyze 3D metal flow in shear die extrusion processes due to difficulties in simulating the more complex material flow. The finite-volume technology in MSC.SuperForge overcomes these difficulties and the package was effectively used to simulate various feeder plate designs for a shear die extrusion process.

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Introduction

In this study, the extrusion process is assumed to be an isothermal and steady state process. These assumptions were used in all the metal forming simulations performed with the two analysis packages representing different analysis methods: the finite-element method and the finite-volume method.

Finite-Element Method

The finite-element method (FEM) for elastic-plastic material property is considered to be an accurate method, but it is generally not very well suited for the severe material deformation typical in many metal-forming processes, and can also result in long CPU time to carry out the computations.

Some codes for computer simulation of metal forming operations (such as DEFORM™-3D) have been established on the basis of a rigid-plastic finite-element method. The assumption of rigid-plastic or rigid-viscoplastic material implies that the flow stress is a function of strain, strain rate, and temperature and that the elastic response of the material is neglected. This assumption is very reasonable in analyzing metal forming problems, because the elastic portion of the deformation is negligible in most metal forming operations.

In the finite-element method, grid points are defined that are fixed to locations on the body being analyzed. Connecting the grid points together creates elements of material, and the collection of the elements produces a mesh. As the body deforms, the grid points move with the material and the elements distort. The finite-element solver is, therefore, calculating the motion of elements of constant mass. Because of the severe element distortion common in metal forming operations, frequent finite-element remeshing is necessary to follow the gross material deformation.

Finite-Volume Method

The finite-volume method has been used for many years in analyzing the flow of materials in a liquid state. However, in recent years, some codes for computer simulation of solid-state metal forming operations (such as MSC.SuperForge) have been established on the basis of this method. In the finite-volume method, the grid points are fixed in space and the elements are simply partitions of the space defined by connected grid points. The finite-volume mesh is a "fixed frame of reference." The material of a billet under analysis moves through the finite-volume mesh; the mass, momentum, and energy of the material are transported from element to element. The finite-volume solver, therefore, calculates the motion of material through elements of constant volume, and therefore no remeshing is required.

Simulations

For evaluation purposes, both DEFORM™-3D and MSC.SuperForge were used to perform a simulation of an extrusion process with a streamlined die design. In addition, because of its capability to handle severe material flow, MSC.SuperForge was used to perform six more simulations of a shear die extrusion process - one simulation using a shear die and five simulations using five different feeder plate dies.

Process Parameters

In addition to the billet and die shape, there are four common process parameters that are identical in all the simulations in order to perform a valid comparison: billet material properties, ram speed, initial temperature, and friction. The excellent formability of aluminum alloys makes them strong candidates for extrusion processes, and as a result aluminum 6061-0 was selected for the billet material since it is commonly used for cold extrusion. Ram speed, initial temperature, and friction values were also all selected consistent with a cold forging extrusion process with no lubrication. A ram speed of 2.5 in/sec was selected. Friction was defined as follows: a shear friction coefficient of 0.2 for contact between the billet and the stationary die and a shear friction coefficient of 0.3 for contact between the billet and the ram.

The flow stress curve commonly used for cold extrusion, $\bar{s}$, is a function of effective strain, $\bar{e}$, and the material constants C,n and is given by

$$\bar{s} = c\bar{e}^{n}$$

where the material constants C,n vary with the specific material or alloy.

The material properties and flow curve shown in Table 1 and Figure 1, respectively, were used in all the simulations performed with DEFORM™-3D and MSC.SuperForge.

Table 1: Material Properties for Aluminum Alloy 6061-0

Quantity	**English units (in/lb/s/°F)**	
Density	klb/in^3	9.75E-4
Temperature	°F	68
Initial Temperature	°F	68
Young's Modulus (E)	ksi	10,100
Min. Yield Stress (S)	ksi	8
Yield Stress Constant (C)	ksi	32.5
Strain hardening exponent (n)	-	0.209
Poisson's Ratio	-	0.33

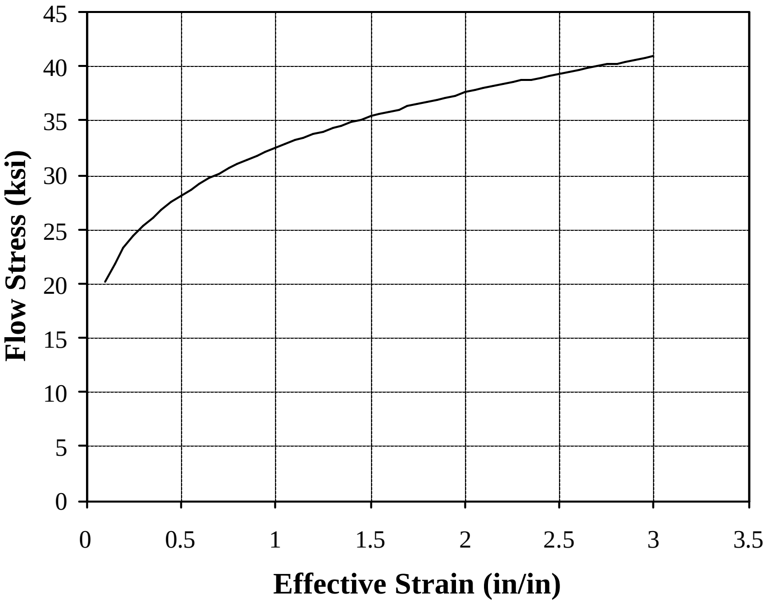


Figure 1: Flow curve for Aluminum Alloy 6061-0

Using DEFORM™-3D

DEFORM™-3D is a commercial package developed by SFTC (Scientific Forming Technology Corporation). It is a finite-element method (FEM) based process simulation system designed to analyze three-dimensional flow of various metal-forming processes. It provides vital information about material and thermal flow during forming processes. The capabilities of DEFORM™-3D have been evaluated and validated by applying it to several isothermal and non-isothermal applications.

Typical DEFORM™-3D applications include forging, extrusion, heading, rolling, and many others. It is designed to model complex 3D material flow. Its simulation engine is capable of analyzing large deformation and thermal behavior of multiple interacting objects during the metal forming process. An automatic mesh generator (AMG) that generates an optimized mesh is included. This facilitates the generation of finer elements in regions where greater solution accuracy is required, thus reducing the overall problem size and computing requirement. AMG, however, only supports one type of mesh - a paver mesh - which does not fit curved surfaces well. As an alternative to AMG, then, DEFORM™-3D accepts isometric tetrahedral meshes generated outside of DEFORM™-3D, and in most cases can remesh these exteriorly generated tetrahedral meshes. In this study, the billet was meshed in MSC.Patran using a solid tetrahedral isometric mesh, since this mesh gives better results than using the AMG paver mesh in DEFORM™-3D.

In addition to the process parameters described in the previous section, setting up the DEFORM™-3D simulation model requires definition of the following simulation control parameters:

Table 2: DEFORM™-3D Simulation Control Settings

Parameter	**Value**
Units	English
Simulation mode	Isothermal
Starting step number	-1
Number of simulation steps	50
Step increment to save	1
Primary die	1
Steps are controlled by	Stroke
Maximum stroke per step	0.1

And setting the inter-object relations (contact definitions) below:

Objects	**Relation**	**Separation**	**Friction**
Die-Billet	Master-Slave	Yes	Shear 0.2
Ram-Billet	Master-Slave	No	Shear 0.3

DEFORM™-3D also requires a suitable memory size to be defined for the integer and real arrays. The approximate memory sizes needed for each of the two arrays are given at the database file generation step. In this simulation, 30 MB and 60 MB were reserved for integer arrays and real arrays, respectively. Checking of the simulation process while it is running is available with the Process Monitor option. It shows the DEFORM™-3D simulation processes that run on the same machine with their current step number and allows for any process to be aborted. At the end of the simulation, the database file that contains all the simulation results data can be browsed using the Post-Processor included in DEFORM™-3D. In addition, displays can be captured and saved as an image file.

Using MSC.SuperForge

MSC.SuperForge is a new software package developed by MSC.Software Corporation for the computer simulation of 3D industrial forging processes. It combines a robust finite-volume solver with an easy-to-use graphical user interface specifically designed for the simulation of 3D bulk forming operations. Forging companies and suppliers worldwide are effectively utilizing MSC.SuperForge to successfully simulate the forging of a variety of practical industrial parts. Ohio University was selected as one of the beta test sites for evaluation and testing of this software package.

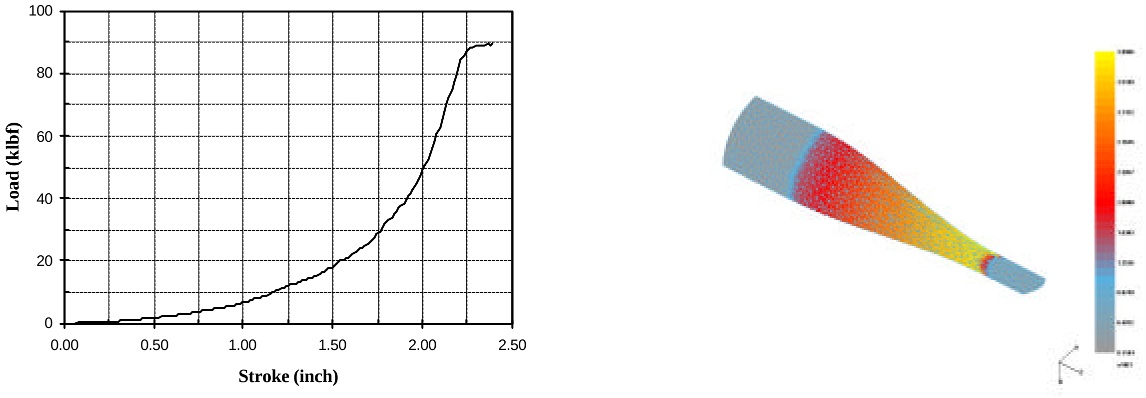
The release of MSC.SuperForge Version 2000 features a new Windows based graphical user interface. Complex forging simulation models can now be set up in minutes, using familiar Windows drag & drop functionality. Once model setup is complete, the simulation can be started from within the user interface, and results can be visualized on the fly as the simulation progresses. Material flow can be visualized and animated with workpiece results such as stress, strain or temperature contours superimposed on the material flow animation. In addition, cut-sections can be animated, showing stress/strain/temperature results and potential folds inside the workpiece. Memory settings, workpiece-die interactions (contact), and finite-volume domain generation are all fully automatic and require no user input or intervention.

Simulation Results

The extrusion streamlined die simulation was performed with both DEFORM™-3D (Version 3.0) and MSC.SuperForge (Version 1.0), using the same process parameters. Both simulations were performed on a Silicon Graphics workstation computer. Similar numbers of finite elements and finite volumes were used in each simulation in order to assure a valid comparison of the two simulation packages. The load-stroke curve and two different contour plots - effective stress and effective strain - were selected as the basis for comparison of the DEFORM™-3D and the MSC.SuperForge simulation results.

Streamlined Die Extrusion - DEFORM™-3D Results

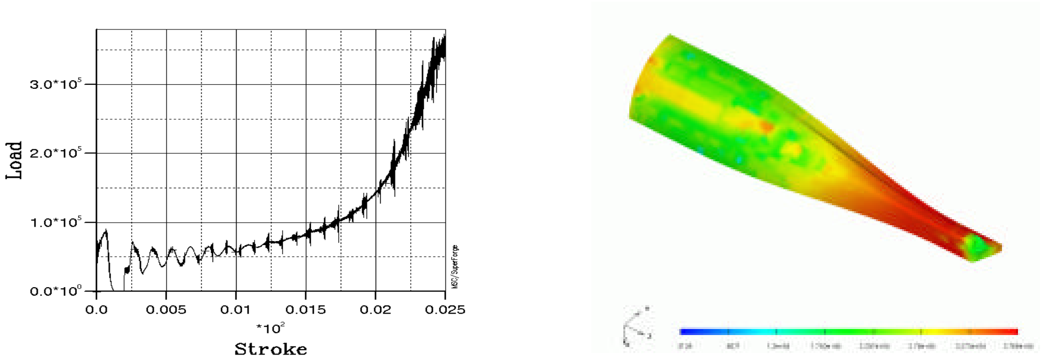
Simulation results are easily visualized using the post-processor of DEFORM™-3D. This post-processor supplies the user with six different types of contour plots: stress, strain, strain rate, velocity, temperature, and damage. It also supplies x-y curves for variables such as press load and/or velocity versus forming process time and/or press stroke.



Figures 2 & 3: Load-stroke curve and effective stress distribution for DEFORM-3D streamlined die extrusion simulation

Streamlined Die Extrusion – MSC.SuperForge Results

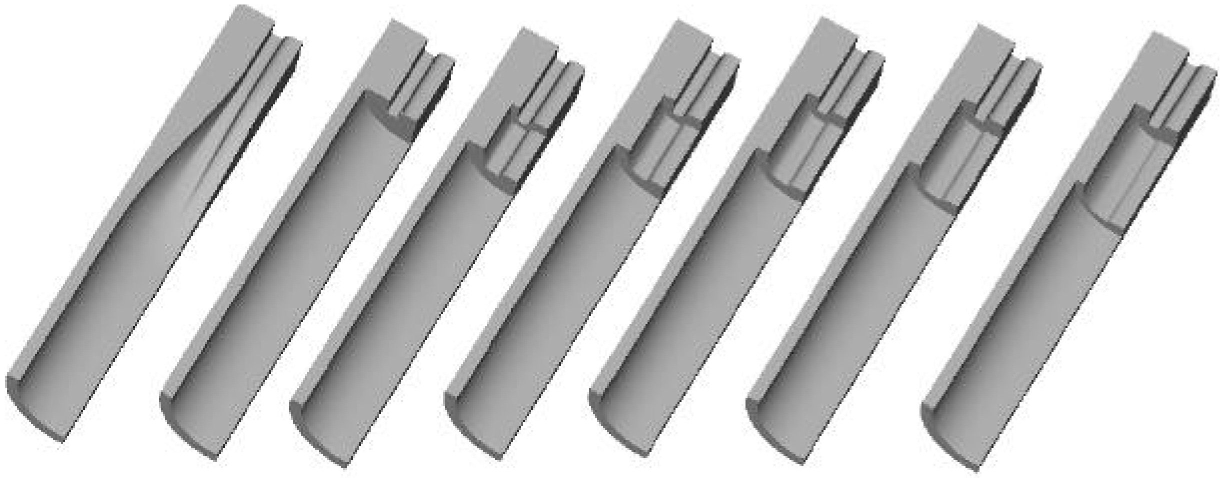
The new Windows look and feel of MSC.SuperForge makes results visualization surprisingly easy. In addition to visualization of stress, strain, strain rate, velocity and temperature contours, MSC.SuperForge also provides density, pressure and die contact contour plots. The die contact contours are especially useful to visualize die fill/underfill in 3D. MSC.SuperForge also provides x-y curve functionality for load-stroke plots, etc, but the user cannot change the range or labels of the automatically generated plot axes. In addition, the load-stroke plot often includes dynamic oscillations, which sometimes makes this result interpretation more difficult.



Figures 4 & 5: Load-stroke curve and effective stress distribution for MSC.SuperForge streamlined die extrusion simulation

Shear Die Extrusion - MSC.SuperForge Results

Until now, 3D simulation of an extrusion process using a shear die was difficult at best. This type of metal forming process is characterized by severe metal deformation that, for the most part, leads to remeshing problems with conventional finite-element based forging simulation packages. Most of the current metal forming packages, including DEFORM™-3D, are still incapable of performing 3D extrusion process simulations using shear dies. With its finite-volume method and no remeshing, on the other hand, MSC.SuperForge has the capability to handle the severe metal deformations characteristic of a shear die extrusion process. As a result, MSC.SuperForge was used to perform six 3D simulations of a shear die extrusion process - one simulation using a shear die and five simulations using a shear die with five different feeder plate designs. For comparison, Figure 6 shows the streamlined extrusion die used in the MSC.SuperForge evaluation study in the previous section, along with the six different shear die designs used in this part of the study.

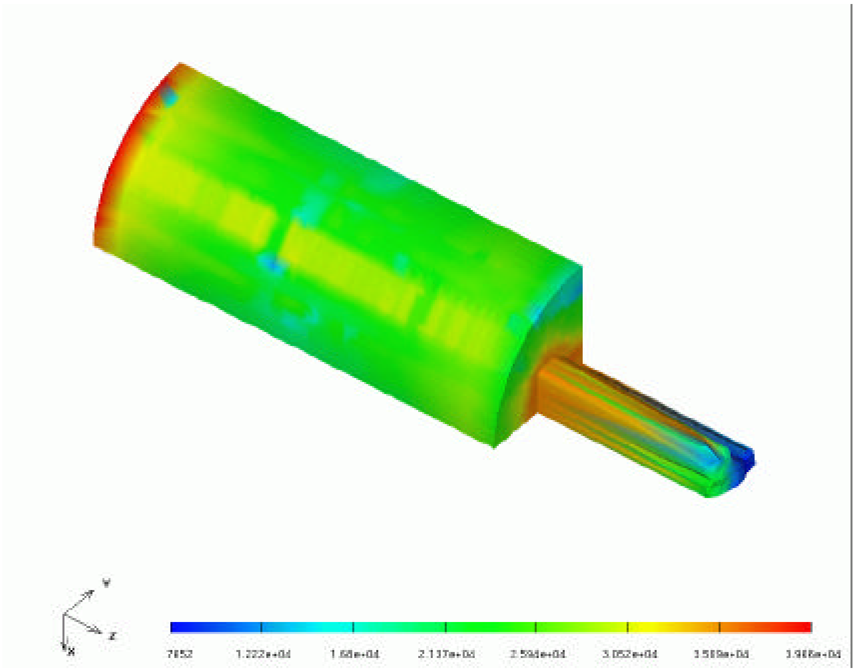


Streamlined Die **Shear Die with no Feeder Plate** **Shear Dies with Different Feeder Plate Designs**

Figures 6: Streamlined die and shear die designs used in the MSC.SuperForge shear die extrusion simulations

The various cross-sections of the feeder plates on the shear dies were chosen to correspond with selected cross-sections along the length of the streamlined die. An extrusion simulation for each shear die design, including the no feeder plate design, was then performed with MSC.SuperForge to determine the optimal feeder plate design.

MSC.SuperForge results of the shear die extrusion simulations indicate that the stress distribution in the shear die extrusion process is concentrated at locations along the extruded billet. Results for the shear die with no feeder plate design are shown in Figure 7. The maximum effective stresses occur at the abrupt change in billet cross-section where the shearing action begins and also at the contact surface between the billet and the ram. The maximum and minimum stress values are 39.66 ksi and 7.652 ksi, respectively. For comparison, results from the MSC.SuperForge streamlined die simulation indicate that the effective stress distribution changes gradually along the extruded billet and is inversely proportional with the extruded cross-sectional area. The maximum and minimum effective stress values are 37.66 ksi and 3.139 ksi, respectively.



Figures 7: Effective stress distributions for MSC.SuperForge simulation of shear die Extrusion with no feeder plate

The overall range of results for the shear die with feeder plate extrusion simulations are as follows:

Maximum effective stress:	37.49-54.00 ksi
Maximum effective strain:	1.98-4.56 in/in
Maximum ram load:	370-600 klbf

The maximum values all occur for the feeder plate design with a cross-section corresponding to the cross-section at the midpoint along the length of the streamlined die. The minimum values occur for the feeder plate design with a cross-section corresponding to the cross-section at a point 2.4615 inches from the wide cross-section end of the streamlined die.

Conclusion and Discussion

Two different 3D forging simulation packages, DEFORM™-3D and MSC.SuperForge, based on finite-element and finite-volume technologies, respectively, were evaluated using a streamlined die extrusion process. The simulation results obtained from each package were comparable, as shown in Table 3. The maximum effective stresses ($\bar{s}_{max}$) and the maximum ram load (P_{max}) were very similar, while the maximum effective strain ($\bar{e}_{max}$) was slightly different.

The CPU time for the MSC.SuperForge simulation, however, was significantly less than the CPU time for the comparable DEFORM™-3D simulation.

Table 3: Comparison of DEFORM™-3D and MSC.SuperForge Simulation Results for a Streamlined Die Extrusion Process

Variable	**DEFORM™-3D**	**MSC.SuperForge**
$\bar{s}_{max}$	38.966 ksi	37.660 ksi
$\bar{e}_{max}$	2.415 in/in	2.021 in/in
P_{max}	360,000 lbf	360,000 lbf
CPU time	21 hours	9 hours

In addition, six shear die extrusion processes using different feeder plate designs were simulated with MSC.SuperForge in order to study the effect of different feeder plate cross-sections on the material flow. These simulations were performed only with MSC.SuperForge since its finite-volume technology can accommodate the gross material deformation in shear die extrusion processes without encountering remeshing difficulties or convergence problems.

From a comparison of the MSC.SuperForge extrusion simulation results using the streamlined die, the shear die, and the optimized shear die with feeder plate, it can be concluded that using a streamlined die has no significant advantage over using a shear die in aluminum extrusion. In fact, the results for all three extrusion die simulations were close enough to conclude that the streamlined die, with its more complex design and associated higher manufacturing costs, is less advantageous than the shear die, especially the shear die with feeder plate design. These results indicate that shear dies and optimized shear dies with feeder plates are a strong competitor for streamlined dies in aluminum extrusion, since their use results in relatively similar metal flow characteristics and they are easier to design and less expensive to manufacture.

Finally, the results of this study also indicate that MSC.SuperForge, with its new finite-volume technology, gives results very close to the results obtained with a validated analysis package, DEFORM™-3D. The simulation CPU time required by MSC.SuperForge, however, was less than half the CPU time required by DEFORM™-3D in performing identical simulations using the same workstation computer. Moreover, the finite-volume technique used in MSC.SuperForge eliminates the meshing problems that makes simulation of metal-forming processes with severe deformation, such as shear die extrusion, difficult and impractical for finite-element based software packages.

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