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Application of The Finite Volume Method to Upset Forging of Cylinders.

The Finite Volume Method has been applied to Cylinder upsetting. The predicted shape and die loads are compared to experimental results. The simulations are performed with ***MSC.SuperForge 2000***

Introduction

For several years now, the Finite Volume Method has been successfully used to predict the metal flow during the forging of complex 3D and Axissymmetric products. It has been shown that the Finite Volume Method is correctly predicting material flow, die fill, the extend of flash, and folds [1-2]. It has also been shown that the Finite Volume Method is a very fast and robust solution method, making it possible to use 3D simulations in a production environment.

The simulations performed in [1-2] are all based on a 1st order implementation of the Finite Volume Method. With the release of MSC.SuperForge 2000 (due in may 2000), a 2nd order implementation of the Finite Volume Method will become available.

In this paper, results of cylinder upsetting will be presented, using both the 1st order as 2nd order implementation. The results will be compared to experimental data.

Nomenclature

U	= material velocity
dUi/dXj	= material velocity gradient
τ	= friction shear stress, $\tau = \alpha \cdot \sigma Y$
α	= plastic shear friction coefficient
σY	= yield stress
m	= $\alpha * \sqrt{3}$ (Friction coefficient as defined in [3])
V_0	= upset velocity
$\bar{\varepsilon}$	= effective plastic strain
S	= Minimum Yield Stress
C	= Yield Constant
N	= Strain Hardening Exponent

Metal Flow in Upset Forging

Extensive theoretical and experimental work has been done in upset forging of rings and cylinders [3-8]. Because of its simple geometry and its experimental repeatability, it is possible to study the effects of different parameters on the forging process. A significant difference was found between the behavior at room temperature (cold forging) and at elevated temperature (hot forging). This difference is mainly caused by the difference in material behavior and the effects of die chilling.

At room temperatures, most metals are not dependent on the strain-rate with which it deforms, and thus the type of equipment used does not significantly influence the metal flow. At elevated temperatures however, most metals are dependent on the strain-rate, which results in different behavior at different die velocities.

It has also been shown [5] that at high deformation velocities, both non-uniform heat generation and inertia forces have an important influence on the metal flow.

Requirements for Upset Simulations

Due to the characteristics of metal flow in upset forging, as described in the previous section, the following aspects of the forming process need to be taken into account by the simulation program:

	Cold	Hot
Elastic-Plastic material behavior	X	X
Yield stress dependent on strain	X	X
Yield stress dependent on temperature	X	X
Yield stress dependent on strain-rate		X
Die Velocity and the die velocity profile		X
Non-Uniform heat generation		X
Inertia Forces		X
Die Chilling		X

Table 1: Analysis requirements for Upset Simulations

Most theoretical analysis methods are not well suited to solve the more complex hot forging process. Mostly, inertia forces are ignored, and often the strain-rate dependency of the material is difficult to capture, or leads to difficulties in reaching a solution. (The analysis method might not reach a solution).

The Finite Volume Method, implemented in MSC.SuperForge uses an explicit time integration scheme, and takes all the above mentioned aspects into account. It does not suffer from convergence problems, even when strain-rate dependency or inertia forces play a dominant role. It is thus well suited to simulate the metal flow in both Cold and Hot Forging, which has been shown in [1-3].

Apart from metal flow, a second important aspect of the forging process is the force required to form a product. This force is commonly referred to as the ‘die load’. The prediction of die load is important in a production environment to decide if a product can be formed on a certain press, or to decide if multiple stages are required.

Numerical Procedures of MSC.SuperForge

MSC.SuperForge was developed based on finite volume rather than finite element technology. Unlike a traditional finite element mesh which distorts while attempting to follow the deformation of material, the mesh is a fixed frame of reference and material simply flows through the finite volume mesh. This unique distinction makes MSC.SuperForge particularly suited for simulating the gross material deformations inherent in forging operations, and at the same time completely eliminates the need for volume remeshing techniques.

MSC.SuperForge has both a 1^{st} and 2^{nd} order acoustic-advection solver. Evolution of stress and impulse waves is done by the acoustic part and evolution of material is provided by the advection part. The face values of the finite volume elements are solved from the Riemann problem posed at the element faces. The 1^{st} order solver is based on the so-called simple Riemann solution whereas the 2^{nd} order solver is based on the generalised Riemann problem. In brief, the latter includes gradients for both internal material velocities and material surface velocities. In the 2^{nd} order solver the advection equations are solved with 2^{nd} order upwind scheme using MUSCL [9].

The updated velocity field is used in the advection solver. Monotonicity is preserved by the nonlinear limiting function Superbee. A more comprehensive description of the technology can be found in [1] and [2].

Cylinder Upsetting

In [3] the experimental results are presented for cylinder samples being upset between hardened, flat, parallel steel plates, under a 200,000-lb Instron testing machine at 0.2in/min (8.5e-5 m/s) ram speed. The material of the specimens is a strain-hardening material, 1100 F aluminum alloy. The specimens are machined from bars that were annealed at 850 F for 1.5 hr and furnace cooled. The material data used in the simulation is given by:

Young's Modulus = 6.925e10 N/m2
Poisson's Ratio = 0.33
Density = 2699 kg/m3
Yield Stress = $\max(S, C*\bar{\varepsilon}^{N})$ *(COLDMAT-Form 2)*
Minimum Yield Stress (S) = 5.5e7 N/m2
Yield Constant (C) = 1.5e8 N/m2
Strain Hardening Exponent (N) = 0.245

Initial Temperature = 293 K
Environmental Temperature = 293 K
Heat Transfer/Conduction not included in the model.

In [3] two frictional situations were tested, dry and with MoS2 spray. However, since the results of the dry and lubricated case were practically identical, only the dry case will be evaluated, with a plastic shear friction coefficient given by:

Plastic Shear Friction (α) = 0.577 *($m=\alpha*\sqrt{3}=1.0$; m is used in [1])*

The maximum stroke of the ram is 1.2-in.

The cylinders have a 1.5-in diameter, and a 2.25-in height (see Figure 1).

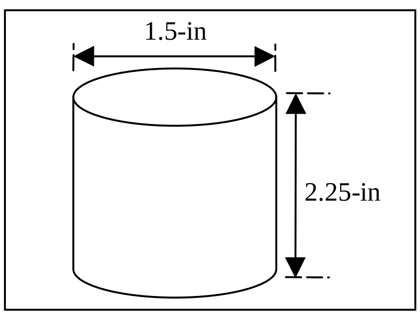

Figure 1: Dimensions of a cylinder sample

Because of the symmetry, only right upper half of the sample is analyzed.
The analysis is done with a Finite Volume element size of 0.002 m (=0.078-in).

Solution Algorithm	CPU Time
1st Order	42 sec
2nd Order	193 sec

Table 2: Required CPU times for cylinder upset Analysis
The simulations are performed on a laptop computer with a 450 Mhz, Intel pentium III processor.

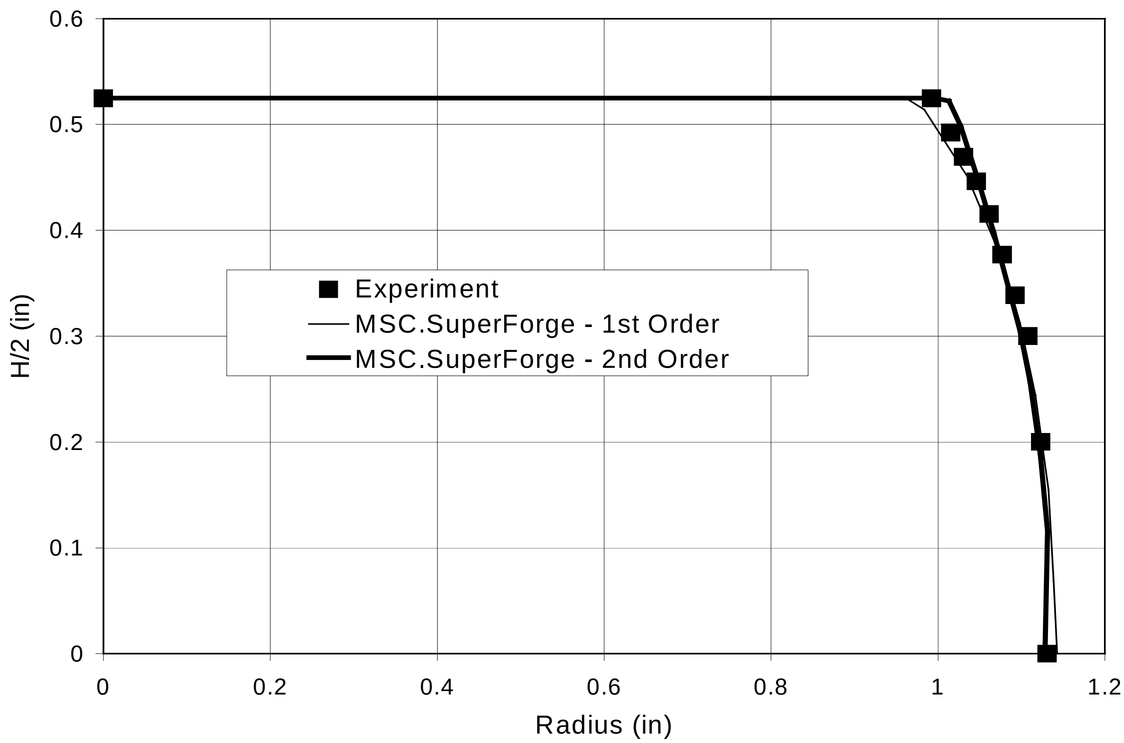

Figure 2: Bulge profile of cylinder upsetting
(dry, α=0.577)

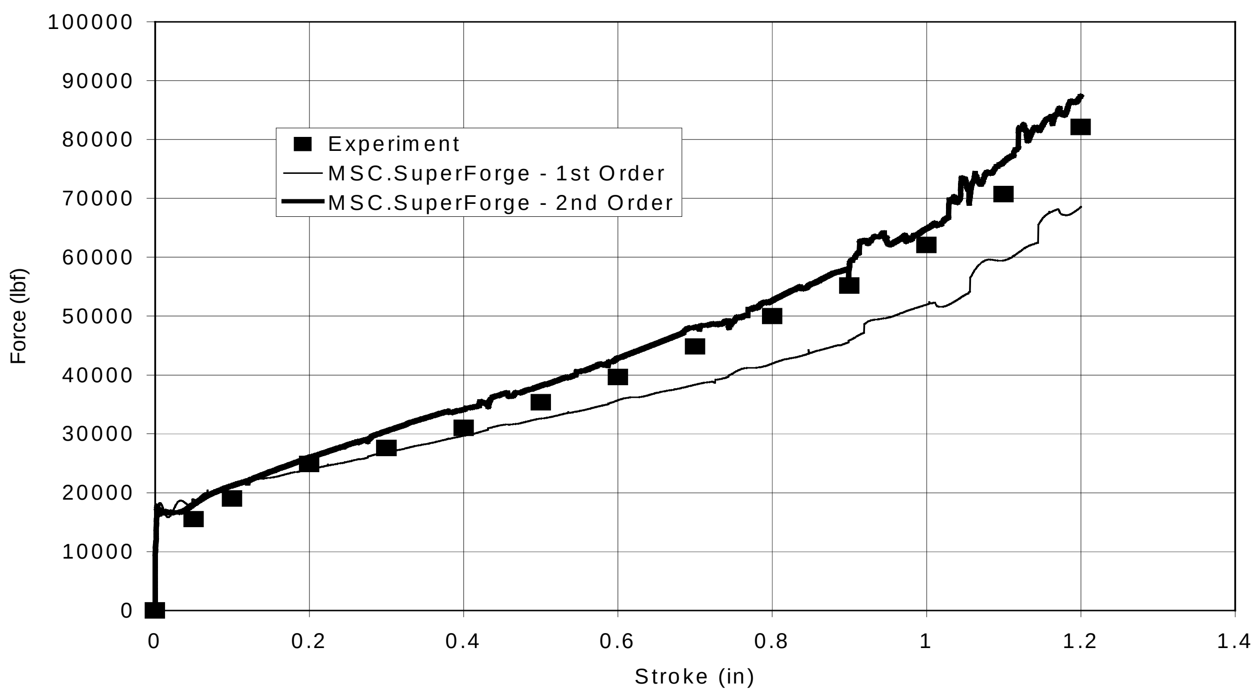

Figure 3: Die Load for cylinder upsetting
(dry, α=0.577)

Conclusion

Results have been presented of cylinder upset forging, using both a 1st order and a 2nd order implementation of the Finite Volume Method. Comparisons have been made with experimental data for the die loads and for the final shape. It has been shown that both methods accurately predict the metal flow and the die load. The 2nd order method is slightly more accurate, but requires more CPU time.

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