Computer-Assisted Design of Pre-Form and Finisher Dies for Cold Forging of Aluminum

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1.0 *Introduction*

1.1 *Background*

Forging is an important mechanical process for part forming because of the superb mechanical properties of forged parts. Thus, it is valuable for metallurgical engineers to be familiar with the forging process. This paper will outline an experimental forging problem and attempt to define a viable solution.

One of many challenges involved in performing forging is the complex mechanics. Specimen and tooling geometries can be very complicated and often hard to model. To avoid wasted time and costly re-machining of dies computer simulation of forging is commonly used.

In order to accurately simulate a complex forging process, finite element analysis (FEA) is often used. One of the most useful programs, and the one used in this project, is DEFORM 2-D. As the name indicates, this program models a forging process in two dimensions. This two-dimensional analysis can be applied to parts which are deformed in plane-strain (no stress in the 3rd dimension) or parts which are axisymmetric, as is the case here.

1.2 *Problem*

The problem faced in this paper is to fully fill a die with the least amount of force. The die shape is shown in Figure 1. Both laboratory experimentation and computer simulations were used to solve the problem.

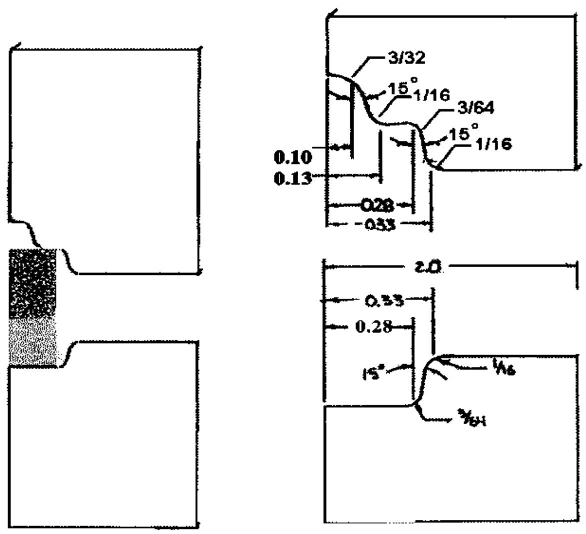

Figure 1. Experimental Die Geometry (measurements in inches).

2.0 *Laboratory Experimentation*

2.1 *Procedure*

In order to accurately model the cold forging process, it was necessary to obtain experimental data. For this reason, several cylinders of 1100 aluminum were cold forged to the desired shape using an Instron uniaxial compression machine. A die of known geometry was used and the surface finish of the die was noted. An oil and graphite lubricant was applied to the top and bottom surfaces of the die. Considering the die surfaces and the lubricant used, the coefficient of friction between the cylinders and the die material was estimated to be 0.03. The maximum loads for the four tests were 35,000, 61,000, 85,000, and 115,000 pounds, and resulting dimensions of the workpiece were recorded.

2.2 *Results*

Table 1 shows the initial specimen geometry of the four aluminum cylinders. Table 2 shows the final geometry of the workpiece. Refer to Figure 2 for dimensional references.

Table 1. Initial Specimen Geometry		
Specimen	Height (in)	Diameter (in)
1	1.1270	0.5660
2	1.1360	0.5655
3	1.1300	0.5655
4	1.1320	0.5650

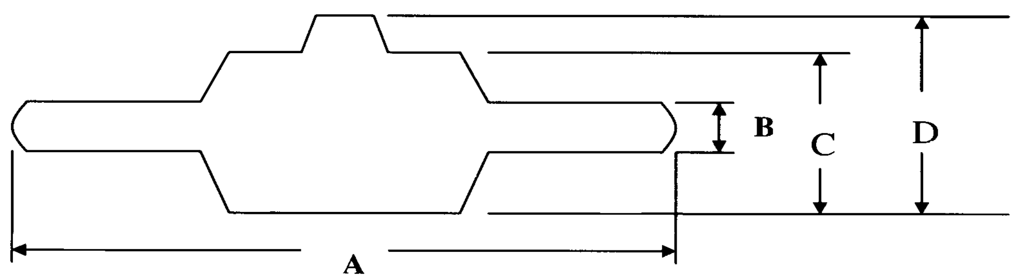

Figure 2. Final Part Geometry with Dimensional References.

Table 2. Final Specimen Geometry (measurements in inches)				
Specimen	A	B	C	D
1	1.1315	0.2010	0.4985	0.6590
2	1.2855	0.1530	0.4490	0.5690
3	1.3890	0.1305	0.4275	0.5230
4	1.4748	0.1155	0.4115	0.5410

From visual inspection, it was determined that the die had not filled for any of the four tests. There was also a large amount of material wasted in the flash. Figure 3 shows a photograph of the samples, in the same order as given in Table 2.

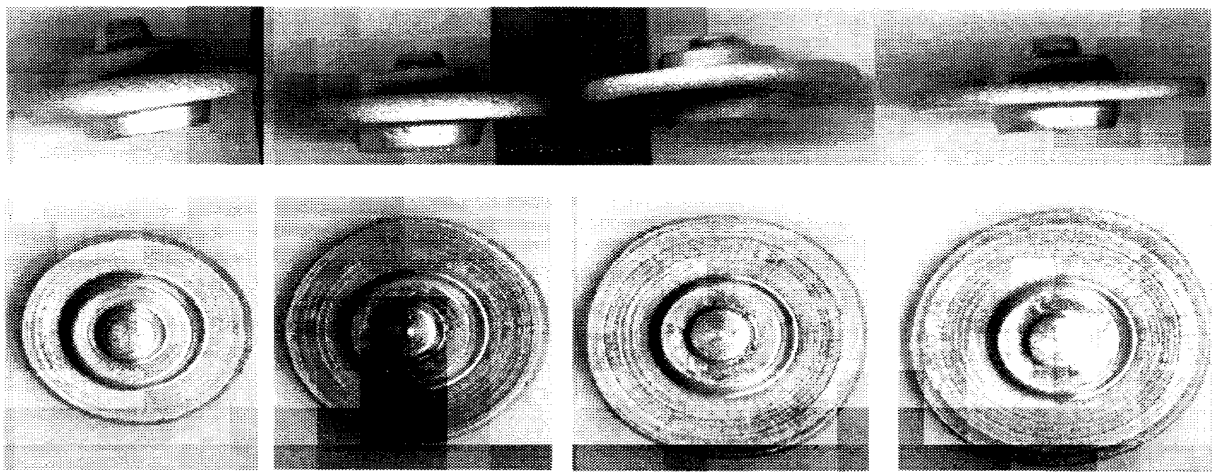

Figure 3. Photographs of Finished Cold Forged Specimens.

3.0 *Computer Simulation*

3.1 ***Procedure***

The process then was modeled in DEFORM 2D and the resulting data compared to the Instron test. To attempt to solve the problem of the lack of die fill, a two step process using both a bust and finish set was simulated.

3.2 ***Results and Discussion***

3.2.1 Single Die

Figure 4 shows the load-stroke curve for the DEFORM simulation. The simulation was run until the flash thickness was 0.1", which was similar to the flash thickness from specimen 4.

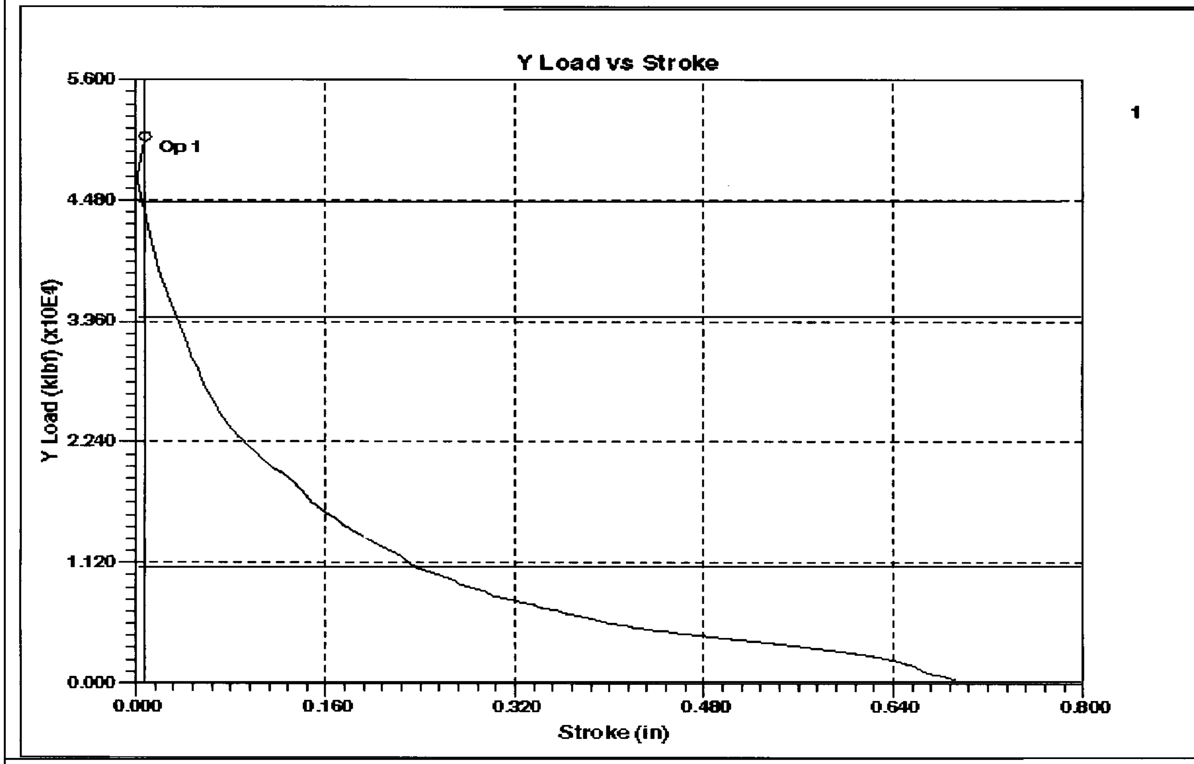

Figure 4. DEFORM Load-Stroke Curve for Single-Die Operation

As Fig. 4 shows, the maximum load that DEFORM predicts is 53,000 pounds. This is inconsistent with the load seen in the laboratory, which was 115,000 pounds for 0.1" flash thickness. One of the possible reasons for the discrepancy is that DEFORM assumes that the friction is constant across the entire die-workpiece interface. This is unlikely, as the lubricant was applied only at the beginning of the stroke and may not have spread into the flash area.

Figures 5 and 6 show the final step of the DEFORM simulation at the maximum force of 53,000 pounds. The lack of die filling is compatible with the experimental findings, as Figure 6 indicates.

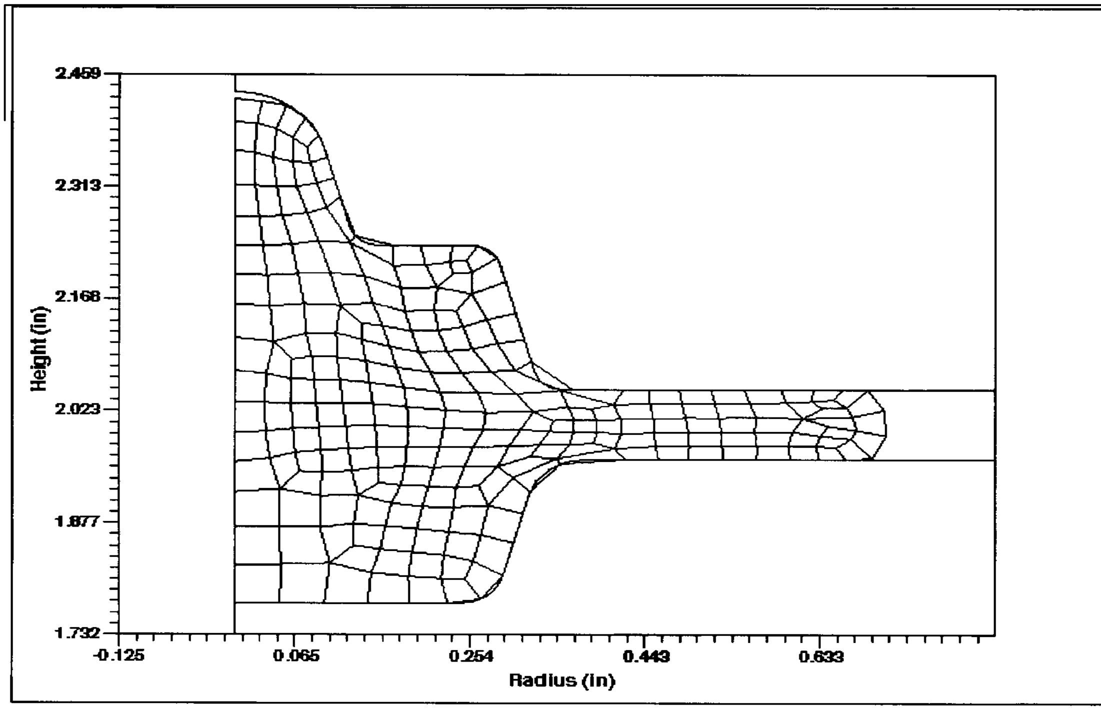

Figure 5. DEFORM Single Die Final Part Shape

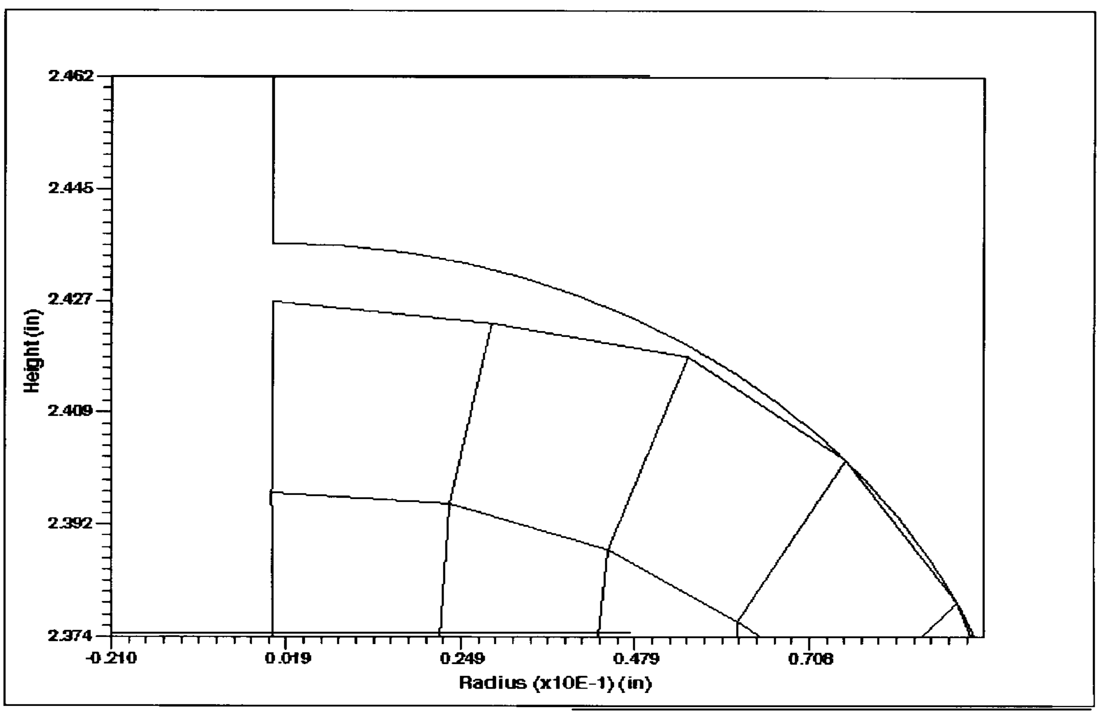

Figure 6. Close-up of Non-Fill Area in Single-Die Simulation

3.2.2 Two Dies

To solve the die-fill problem, a system of two dies and a different incoming stock geometry was used. The geometry of the aluminum cylinder was changed to a radius of 0.2" and a height of 1.5" (the volume remained unchanged). The buster die is shown in Figure 7. The lower die has a 5° draft angle to facilitate part removal after the forging step.

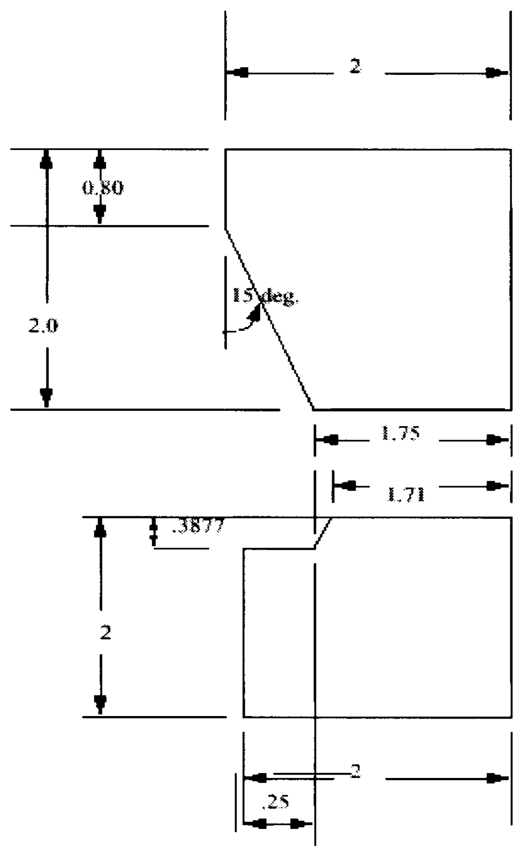

Figure 7. Schematic of Buster Die (measurements in inches).

The shape of the preform was chosen in order to solve the die fill problem. As seen in Figures 5 and 6, the finish die was not filling completely. DEFORM showed that the material was not able to fill the top recess on the die. It was thought that if the top diameter of the cylinder could be reduced then the finish die could be successfully filled. The combination of reducing the radius of the initial cylinder and the pre-form die shape in Figure 7 reduced the top diameter of the forging to 0.174". The end of the pre-form operation can be seen in Figure 8.

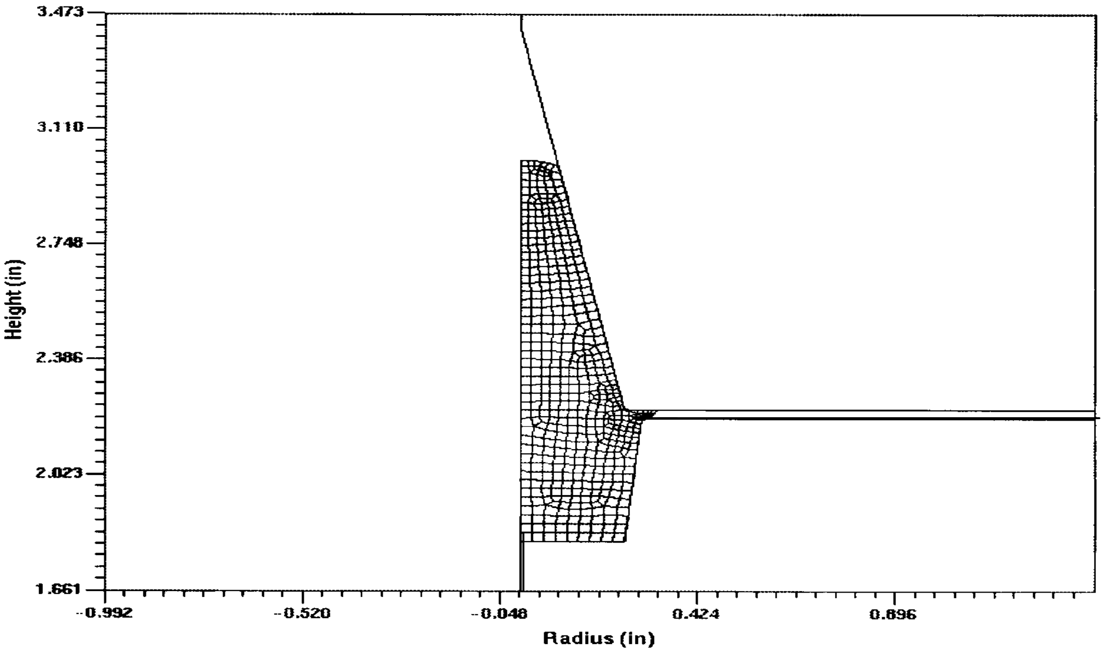

Figure 8. Part Shape After the Buster Step

;utters were included in the finish die in order to reduce the forging load. The utters began 0.042 inches away from the start of the die cavity in both the top and ι dies. A schematic of the preformed part in the finishing die is shown in Figure 9.

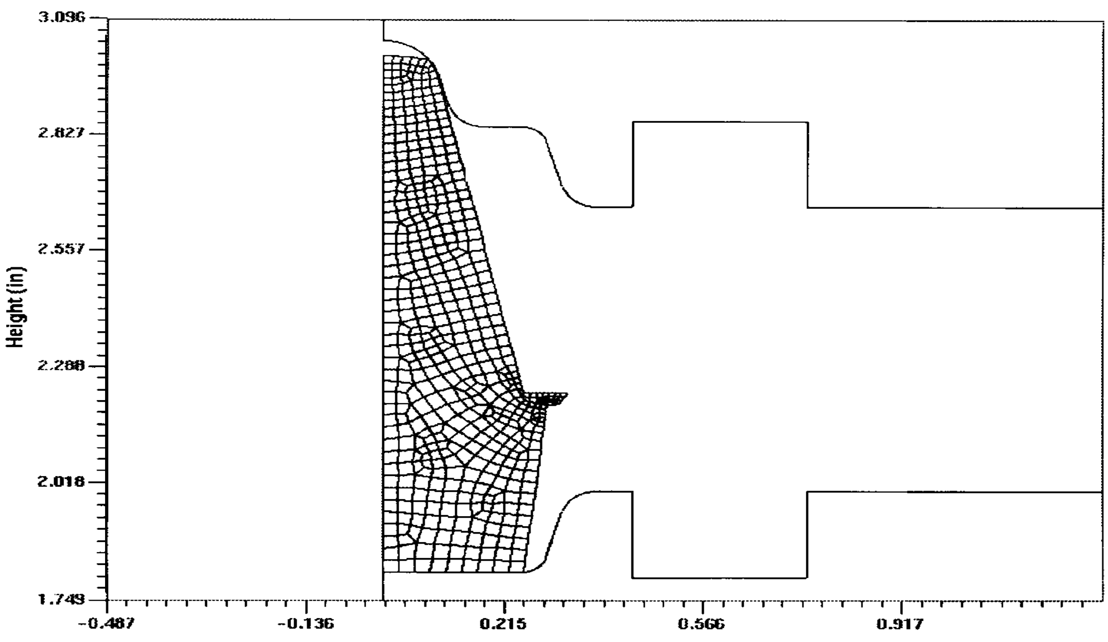

Figure 9. Preformed Part in Modified Finish Dies Before Forging

The DEFORM simulation showed a complete fill of the problem area in the top die. In addition, the small flash created in the buster die flows into the flash gutter in the finishing dies, avoiding the creation of any cold shuts. Figures 10 and 11 show the final step of the finish operation.

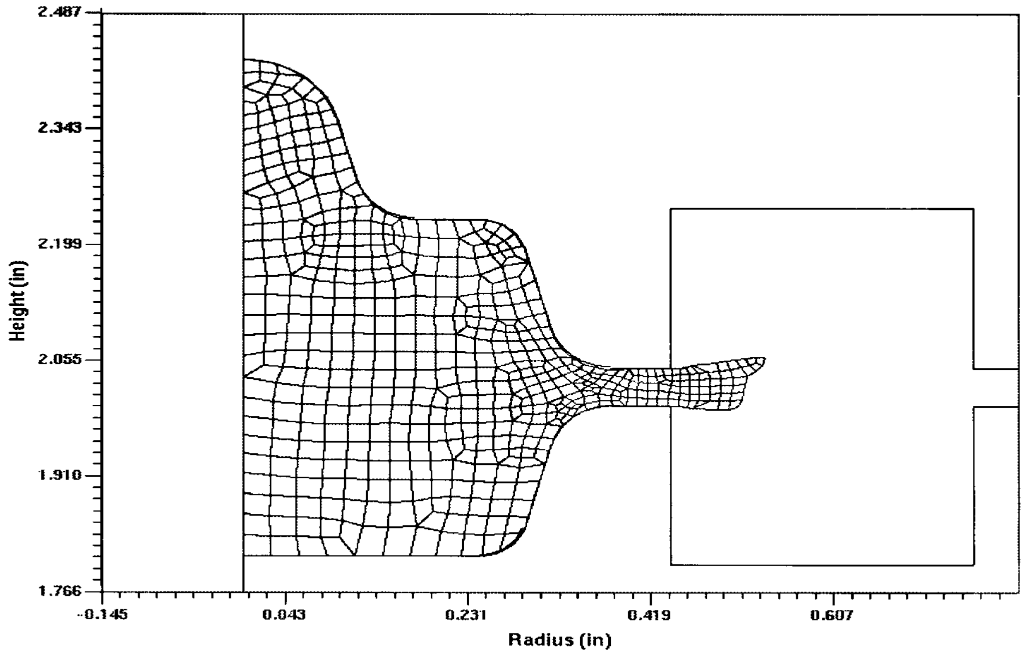

Figure 10. Final Step of Forging Operation

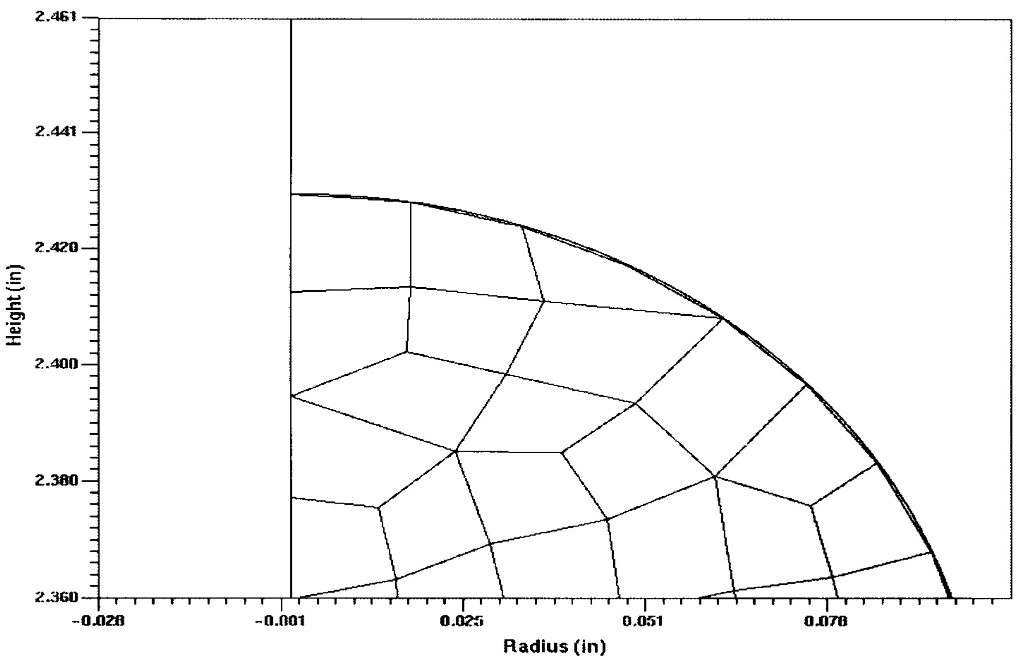

Figure 11. Close-up of Filled Finish Die

As Figures 10 and 11 show, the die was filled successfully. Figure 12 shows that this was accomplished along with a reduction in forging load.

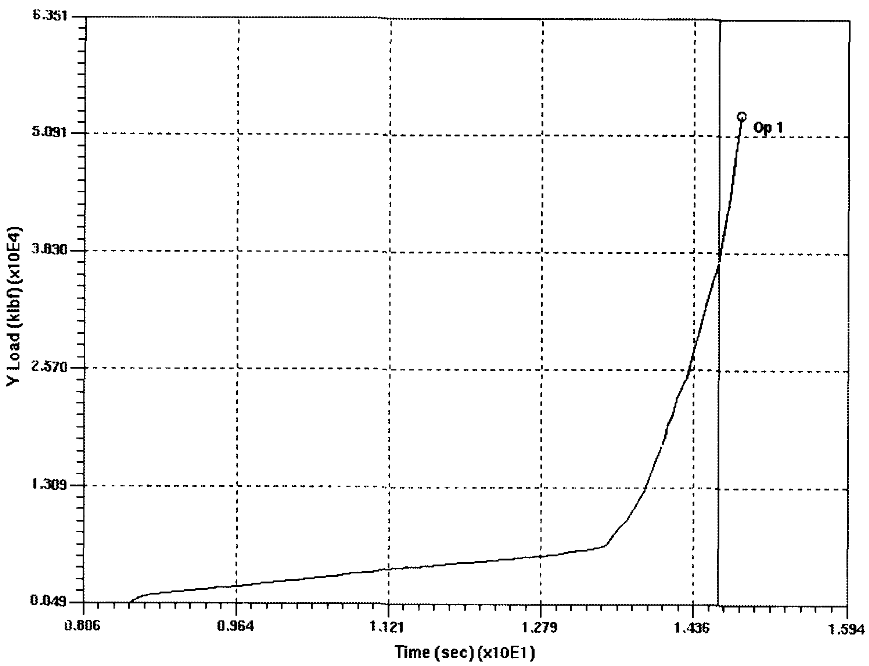

Figure 12. Load-Stroke Curve for Finish Step of 2-Step Process

The vertical line in Figure 12 indicates the point at which the die completely filled. The load that corresponds to this point is 37,300 pounds.

4.0 *Conclusions*

DEFORM 2-D proved to be useful for the die redesign. However, the data developed for the single die DEFORM simulation was not consistent with the experimental data. This may be due to variable friction during the forging experiment. It is unlikely that the flash-die interface remained as lubricated as the forging-die interface. However, DEFORM assumes that the friction remains constant during the entire simulation which predicted lower forging forces.

The two step forging process successfully filled the finish dies. The pre-form step reduced the top diameter of the cylinder so that the geometry better fit within the finish die. The loads necessary to fill the finish die were reduced by using the two-step process. Adding flash gutters to the finish die also served to reduce forging loads.