

# Forging Process Analysis and Preform Design

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## Abstract

The purpose of this paper is to optimize the forging process and reduce the required force to forge the final product. A complex 3- dimensional part was provided by *Queen City Forging Company, Cincinnati, Ohio*. Simulation results predicted that the complex 3D part could be forged in one step, using at least a 900 ton capacity press or higher. Since *Queen City Forging Company* has an 800 ton press, the task was to design a preform and two die sets to manufacture the part using the existing press. *SolidEdge* was used to model the dies while *MSC.SuperForge* was used to simulate the forging process. Several different preforms were designed and analyzed to obtain the final product in two stages with a maximum load of less than 750 tons.

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## **Introduction**

Forging is defined as the process in which metal is plastically deformed with application of temperature and pressure. It is used to change not only the shape but also the properties of the metal because it refines the grain size and therefore improves its structure. Forging is a cost-effective way to produce net-shape or near-net-shape components. Forged parts are used in high performance, high strength and high reliability applications where tension, stress, load and the human safety are critical considerations. They are also employed in a wide range of demanding environments, including highly corrosive and extreme temperatures and pressures.

Various parameters such as complexity of the part, friction between dies and workpiece, type of press, die and workpiece temperature, material of workpiece govern the forging process. Forging process is said to be successful if die cavity is completely filled and stress in the workpiece is less than ultimate stress corresponding to the workpiece material, with minimum force.

Forging analysis software packages like *MSC.SuperForge* is very helpful in optimizing the forging process. Die design is very expensive. With these packages forging process can be simulated. Various dies can be tried and forging process can be analyzed closely. Optimum die set for which die cavity fills completely while maintaining a lower stress can be selected.

## **Methodology**

### **For Single Die**

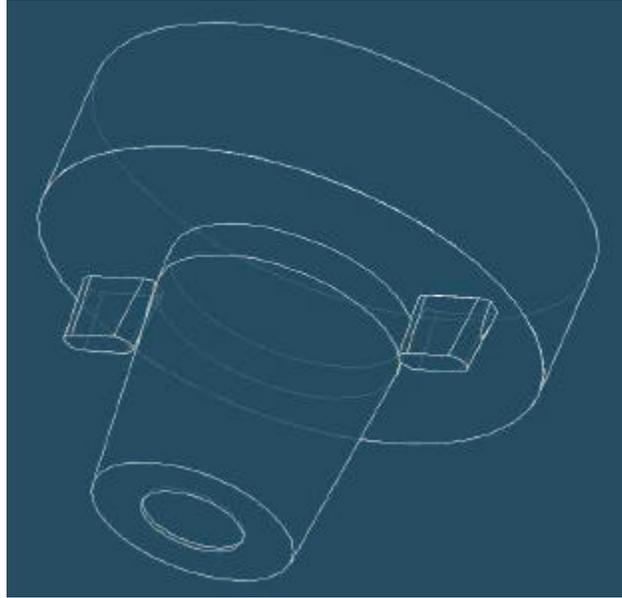
#### **Modeling in CAD System**

3-D modeling software *SolidEdge* is used to model part, billet and dies. *SolidEdge* has an option by which volume of the drawn part can be found. So final part is modeled and required material for the part is found. Final part is as shown in *Figure 1*.

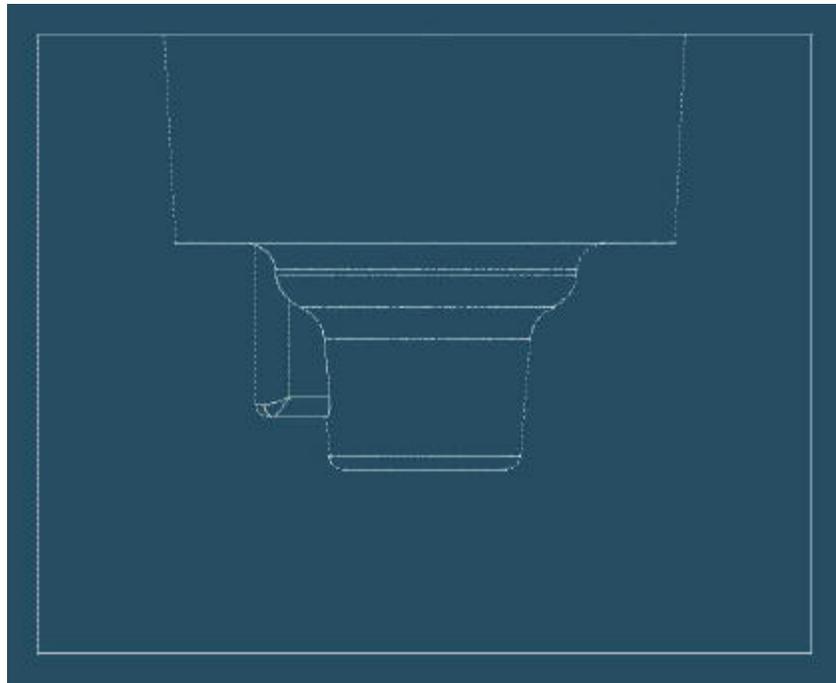


*Figure1: Part*

*SolidEdge* provides option of *boolean* operation by which specific shape can be subtracted or added to the other shape. If the part is simple, *boolean* operation can be used to design the upperdie and lowerdie. For this part lowerdie can be obtained by *boolean* operation but due to partial hole in the part, upperdie cannot be obtained by *boolean* operation. For this project lowerdie and upperdie are modeled without *boolean* operations. Even though *MSC.SuperForge* allows dies and billets to move in *X, Y* and *Z* directions and rotate about *X, Y* and *Z* directions it causes lot of problems in positioning, if they are aligned manually. So care must be taken while modeling dies and billet in *SolidEdge*. The upperdie and the lowerdie are shown in *Figure 2*.



(a)



(b)

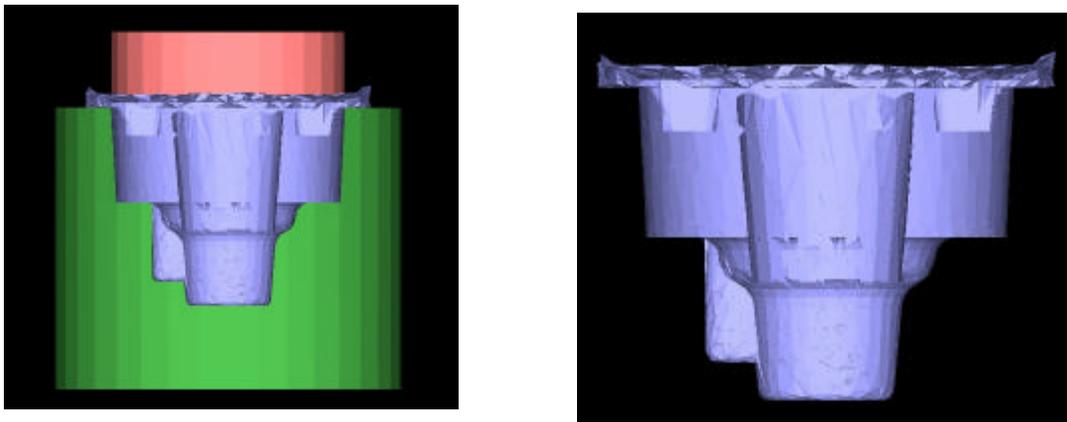
*Figure 2: (a) UpperDie (b) LowerDie*

As the given part has circular cross-section along Z-axis, a cylindrical billet is used. Because forging height to diameter ratio is a very critical parameter for proper die fill, billets with various heights and diameters are tested.

Dies and billets are drawn in such a manner that they are Z-axis aligned. As *SuperForge* accepts only '\*.STL' files, upperdie, lowerdie and billets are saved with 'STL' extension.

## Analysis in MSC.SuperForge

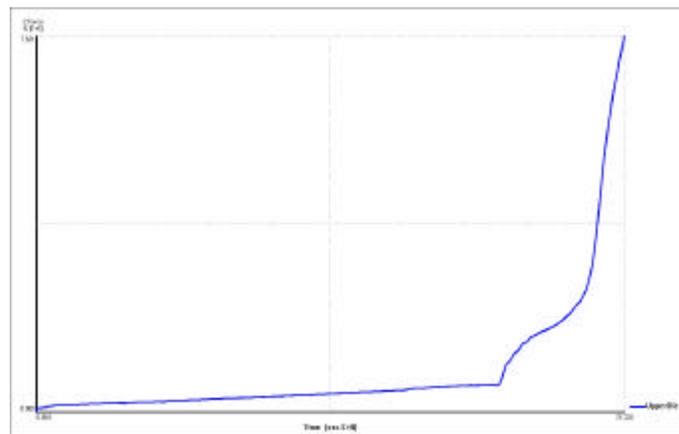
All the files of dies and billets with 'STL' extension are imported to *MSC.SuperForge* database. While importing parts units should preferably be inches. Although *MSC.SuperForge* provides options for other units like meter, millimeter, foot, it works very well and accurately only for inches. It does not matter the unit in which the part is drawn, *MSC.SuperForge* can convert that unit into inches if that option is selected. Appropriate forging parameters like material of die and work piece, type of press, type of friction, friction coefficient, initial die temperature, initial work piece temperature, length of stroke, are provided. Values of the process parameters are given in *Appendix A*. Forging process is modeled in *MSC.SuperForge*. Different billets (different heights and diameters but constant volume) are tried and results are shown in the result table. Once the simulation is done SuperForge provides various options for viewing the results (force-time graph, stress, strain temperature, shape) at any point of time during the stroke. Results show that cavity is completely filled. Final part is shown in *Figure 3(b)*.



(a)

(b)

*Figure 3: (a)SuperForge simulation at the end of stroke (b)Workpiece at the end of stroke Force-Time graph is shown in Figure 4.*

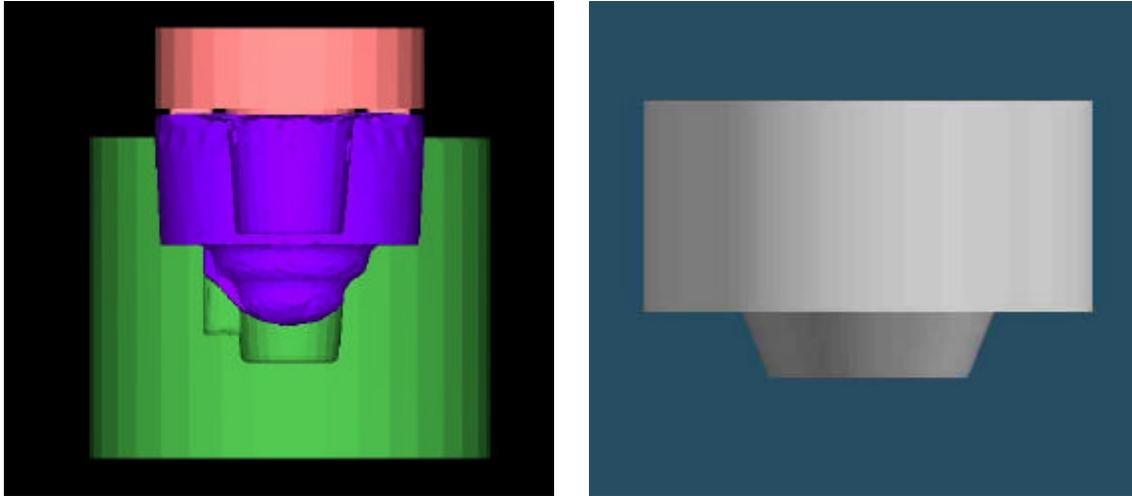


*Figure 4: Force-Time Graph*

From the graph is clear that the maximum force required for the process is  $7.631 * 10^6 N$  which is 857.76 tons.

## For Multiple Dies

Force required to produce a final shape of the part in one step is very large. Thus it was decided to start with a preform for reducing the force requirement. From the *Force-Time graph* it is clear that required force increases significantly after 29.22 seconds. *MSC.SuperForge* provides options to view the shape of the work piece at any point of time during the stroke. Shape of the work piece after 29.22 seconds is found. It is shown in *Figure 5(a)*.



(a)

(b)

Figure 5: (a) SuperForge simulation after 24.88 seconds (b) Simplified preform

If this shape is selected as a preform, it might reduce the force. That shape is simplified so that it is easy to forge and less expensive to manufacture dies. Simplified shape is shown in the *Figure 5(b)*. There is one more difference in this preform. Upper face of the preform is without hole. From *Figure 5(a)* it is clear that only little cavity is left at the bottom which is having smaller diameter. So there is no need of applying force on the whole face of the bigger diameter. From various simulations it was found that material movement in Z-direction requires a small force. As the upper face of the preform is solid, force will be applied on smaller area of bigger diameter. And when upper die penetrates the preform the same amount of the material will be pushed down in Z-direction and very small amount of the material will move in lateral direction till the cavity is filled.

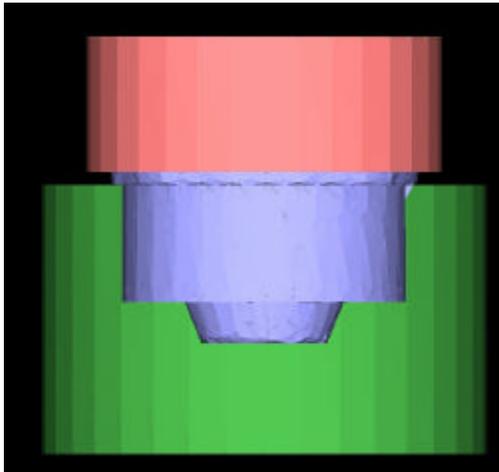
Several other preforms have been tried. But it does not reduce force that much. Various preforms are shown in *Appendix B*.

## Modeling on the CAD System

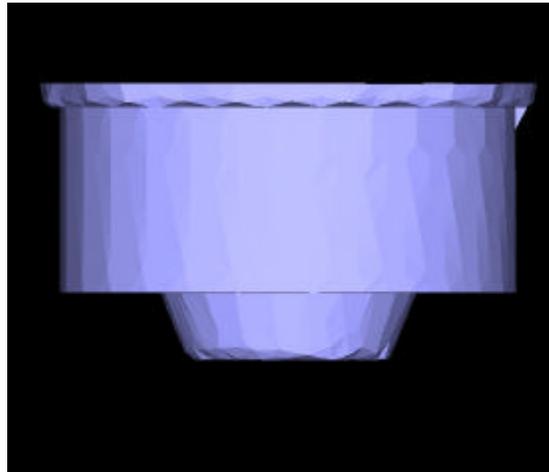
Upperdies and Lowerdies, to produce preform and final shape, are modeled in 3-D modeling software, *SolidEdge*. As the final part is same as the previous case, appropriate billet from previous section is selected for this process. All the dies and billet are saved with *STL* extension.

## Analysis in MSC.SuperForge

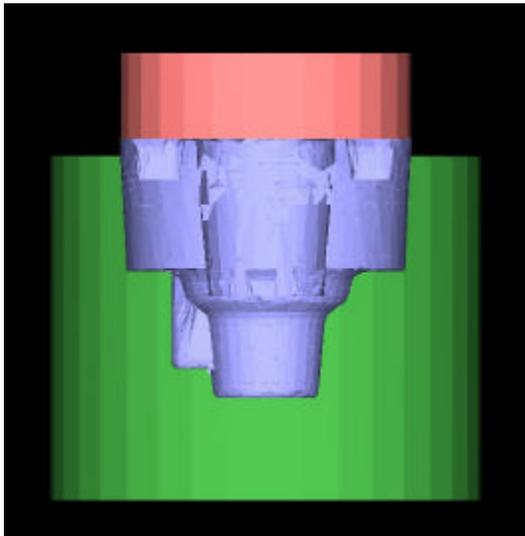
All the files of dies and billet with 'STL' extension are imported in *MSC.SuperForge* database. Appropriate forging parameters like material of die and work piece, type of press, type of friction, friction coefficient, initial die temperature, initial work piece temperature, length of stroke, are provided. Values of process parameters are given in *Appendix A*. Two different forging processes, one to produce preform and the other one is to produce final shape, are modeled. Forging process is simulated and results are analyzed. Final shapes at the end of the stroke are shown in the Figure 6.



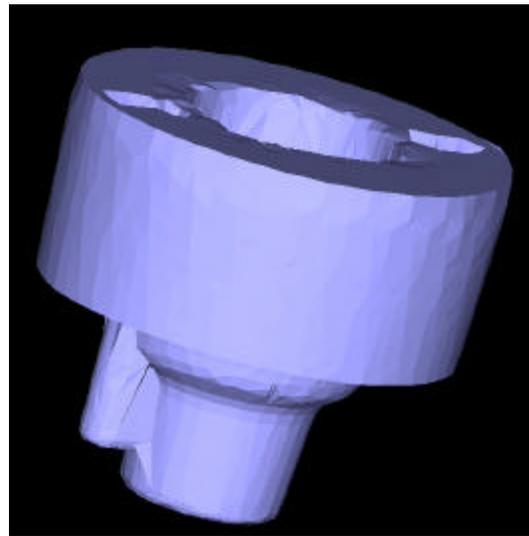
(a)



(b)



(c)



(d)

Figure 6: (a) *SuperForge* simulation at the end of the stroke (preform) (b) Preform at the end of the stroke (c) *SuperForge* Simulation at the end of the stroke (final shape) (d) final shape at the end of the stroke.

Force-Time graphs are shown in Figure 7. It is clear from the graphs that force required for both the processes are  $4.211 \times 10^6$  N which is 473.33 tons and  $2.417 \times 10^6$  N which is 271.68 tons.

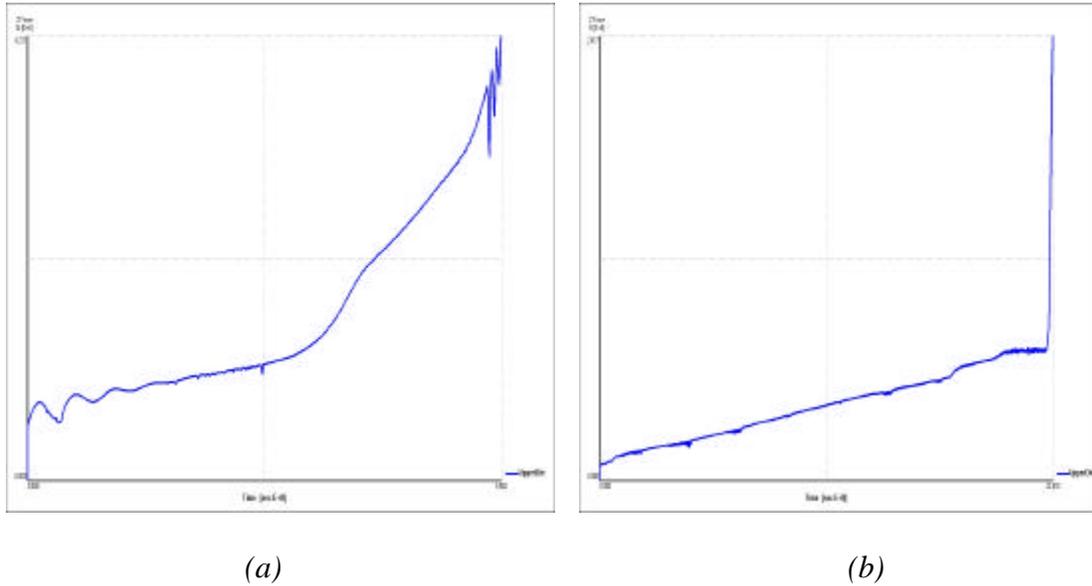


Figure 7: (a) Force-Time graph for preform (b) Force-Time graph for final shape

## Results and Discussion

### Result Table for Single Die:

Number	Billet (inches)		Stress(Pa)	Force(N)	Observation
	Diameter	Height			
1	1.69	5	$2.05 \times 10^8$	$4.31 \times 10^5$	Incomplete
2	2.6	2.53	$2.24 \times 10^8$	$7.631 \times 10^6$	Fully Filled
3	3	1.9	$2.185 \times 10^8$	$6.697 \times 10^6$	Fully Filled

From the above result table it is clear that diameter to height ratio affects significantly the force requirement.

The first simulation could not complete. The reason might be the length of billet. As the slender ratio is very large for this billet, it buckles first. Reverse flow of material might be the reason for incomplete simulation. The second and third simulations were completed but force requirements were very large.

### Result Table for Multiple Dies (Preform):

<i>Number</i>	<i>Shape</i>	<i>Stress(Pa)</i>	<i>Force(N)</i>	<i>Observation</i>
1	<i>Preform1</i>	$2.001*10^8$	$5.648*10^6$	<i>Fully filled</i>
	<i>Final Shape</i>	$2.082*10^8$	$3.307*10^6$	<i>Fully filled</i>
2	<i>Preform2</i>	$1.99*10^8$	$6.59*10^6$	<i>Fully filled</i>
	<i>Final Shape</i>	$2.15*10^8$	$7.168*10^5$	<i>Fully Filled</i>
3	<i>Preform3</i>	$1.94*10^8$	$4.21*10^6$	<i>Fully Filled</i>
	<i>Final Shape</i>	$2.16*10^8$	$2.417*10^6$	<i>Fully Filled</i>

From the above result table it is clear that for case 3 force requirements are minimum to produce preform and final shape. For the second case force required to produce final shape is very less but force required to produce that preform itself is very high.

### Conclusion

From the above discussion it can be concluded that

- Force requirement for a part is very high for a single set of dies.
- Force requirement for the same part can be reduced by selecting appropriate preform shape.
- If company has large capacity press, a single set of dies can be used to forge the part.
- If company has small capacity press, part can be forged by selecting multiple dies.
- Analysis is completed satisfactorily by SuperForge.
- SuperForge is found to be very helpful in simulating and analyzing forging process and selection of appropriate preform shape.

### References

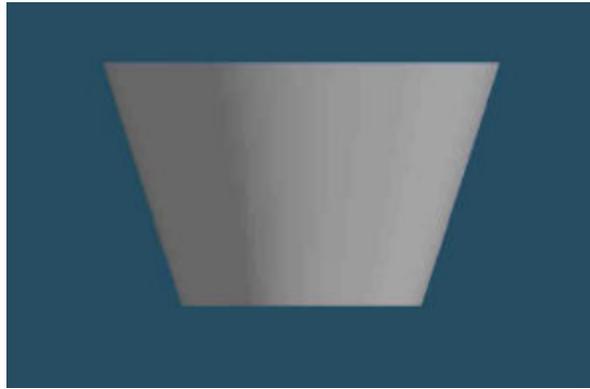
- Jamie Corcoran, Erik Hahn, Barrett Marion, Jonathon Pangbom and Jeffrey Spencer (2000), "Computer-Assisted Design of Pre-Form and Finisher Dies for Cold Forging of Aluminum".
- Catarina Castro, Luisa Sousa, C.A.C. Antonio and J.M.A Cesar de Sa (2001), "An efficient Algorithm to estimate optimal preform die shape parameter in forging".
- Queen City Forging Company, "[www.qcforge.com](http://www.qcforge.com)".
- SolideEdge, "[www.solidedge.com](http://www.solidedge.com)".
- SuperForge, "<http://simulate.engineering-e.com/tutorial/sfviewlets.cfm>".

## Appendix A

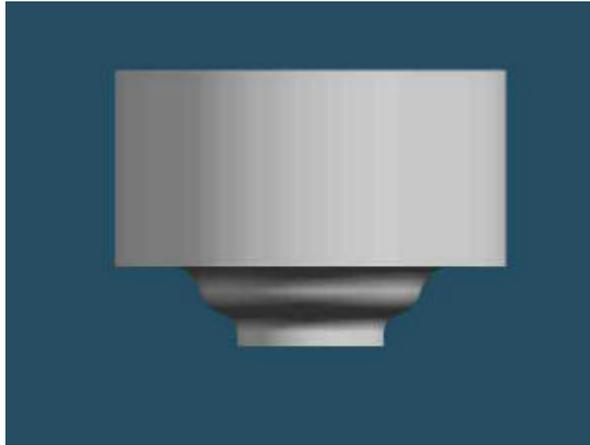
### Forging parameters

Die Material : DIN\_1.3505 (Steel)  
Work Piece Material : AA\_6062 (T=20C) (Aluminum)  
Press Type : Hydraulic Press  
Velocity of ram : 2 mm/sec  
Friction Type : Constant Friction  
Coefficient of Friction : 0.2  
Die Temperature : 300 Fahrenheit  
Work Piece Temperature : 900 Fahrenheit

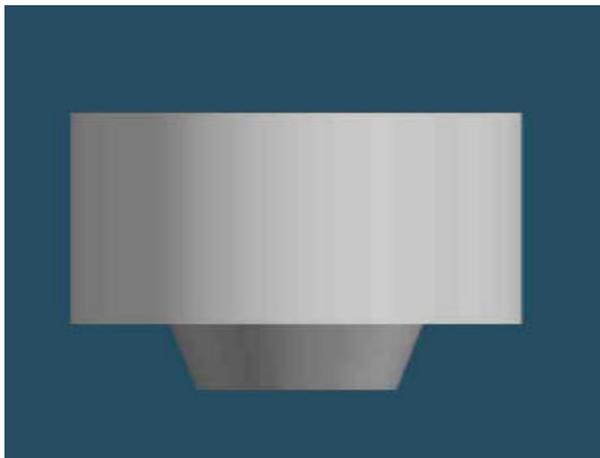
## Appendix B



Preform1

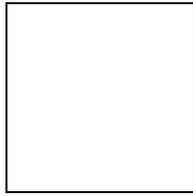


Preform2

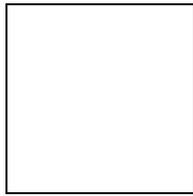


Preform3

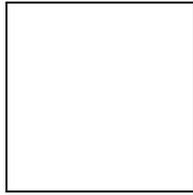
## Appendix C



Final shape using one die set



Preform



Final shape using two dies