# Finite Element Analysis of Sheet Metal under Drawing Processes for Body Brake Booster

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## Abstract

The finite Element Method (FEM) is useful in the analyzing of metal forming problems. In this research, the hydraulic brake system "Body Booster" has been investigated by using an FE program in the prediction of deep drawing process. The materials are made from sheets of steel SPCC with thickness 1.4 mm. and the initial diameter of 323 mm. The body booster requires 11 production processes in the manufacture. The parameters, that had been investigated, were die radius, punch diameter, and friction coefficient. In order to simplify the process, the punch and die in the simulation were assumed to be rigid, which neglected the small effect of elastic deformation. The material properties were assumed to be anisotropic, behaving according to constitutive equation of the power law, Ludwik, and deformed rigid-plastic, which followed Hill's yielding surface. The deformation for Forming Limit Diagram (FLD) was predicted by the Keeler equation. Most of the defects such as cracking, necking, and thinning were found in the second and third processes. In the past, practical productions were performed by trial and error, which involved high production cost, long lead time, and wasted materials.

From the prediction results, the increase in die radius at the second process would reduce the sheet thinning on the bottom of the booster cup in the second process and remove cracks in the third process. The preforming of the booster cup by increasing punch diameter in the second process would increase the formability in the third process. A decrease in friction coefficient can increase the formability of the material in all processes. By using the simulation technique, the production quality, efficiency, and performance has been improved.

**Keywords:** Finite Element Analysis, Forming Limit Diagram, Drawing Processes, Body Brake Booster

## 1. Introduction

Sheet metal forming is one of the most important processes in the production of automotive bodies, kitchenware, etc. Deep drawing is a process in which blanks or workpieces, controlled by a blankholder, is forced into a die cavity in which the thickness is substantially the same as the original material. The strains achieved in a single draw of deep drawing are limited by the maximum tensile stresses which must not exceed the tensile strength of the material [1]. Special processes have been developed which increase the formability limit of the material by shifting the mean normal stress toward the compressive region [2]. Through a redraw technique, the diameter of the cup is decreased, while its height is increased [2]. In this research, a body brake booster has been investigated as shown in Figure 1.

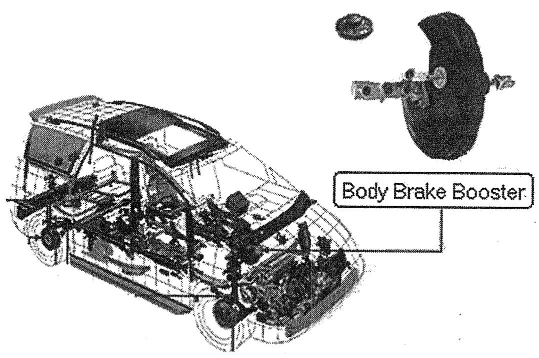


**Figure 1.** Body brake booster in vehicles.

The parts are formed by deep drawing which include 11 successive processes as shown in Figure 2. In the second and third processes, there existed defects on the part such as thinning, cracking, and wrinkling. Thus the processes parameters are determined by using the finite element method to observe their effects.

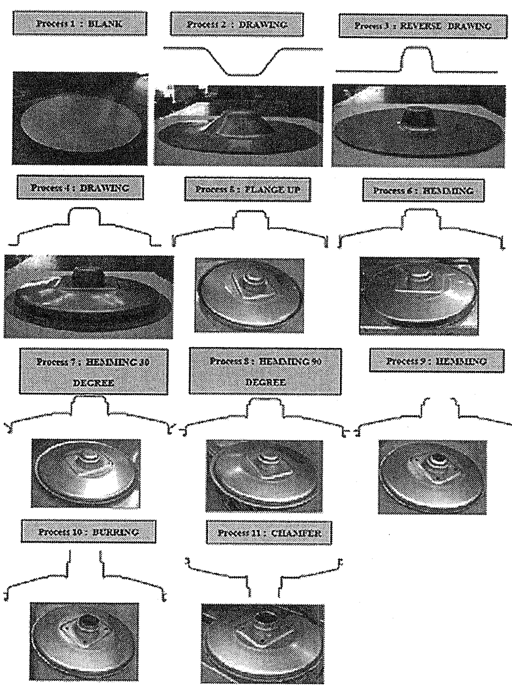


**Figure 2.** 11 Production processes for body booster.

## 2. Materials and Simulation Model

In the deep drawing process, the punch and die are designed according to the part shape. While the blank holder presses on sheet metal on a die, the punch gradually pushes the sheet metal in to the die cavity and forms the sheet into shape [3]. In the second process for the first draw, the punch has a diameter of 120 mm. and the die has a diameter of 125 mm. The sheet has been drawn for a height of 30 mm. In the third process for the redraw, the punch has diameter of 57 mm and the die has a diameter of 60 mm. The sheet had been drawn for a height of 36 mm as shown in Figure 3. The part is made from metal sheet (SPCC) with thickness of 1.4 mm. and the initial diameter of the blank was 323 mm. The material properties were assumed to be anisotropic, behaving according to constitutive equation of power law, Ludwik, and deformed rigid-plastic, which followed Hill's 48 yielding surfaces [4]. The strength coefficient is 369 MPa and strain hardening exponent is 0.16. In addition, some necessary mechanical properties of the material used are Poisson's ratio = 0.3, modulus of elasticity = 210 GPa, yielding stress = 136 MPa. and the plastic strain ratio: $r_0 = 1.54$, $r_{45} = 1.37$ and $r_{90} = 1.74$.

In the current research work, the commercially three-dimensional finite element program, AUTOFORM, was used in the analysis and simulation to investigate the forming characteristics of sheet metal under deep drawing. In the simulation, the punch and die properties were assumed to be rigid, which neglects small elasticity behavior during the forming process. The Forming Limit Diagram (FLD) of Keeler equation [1] has been applied to the prediction of failure during forming analysis. The FLD systematically represents the limit strain, based on localized instability and fractures for a wide region of stress paths. FLD is expressed as a curve in the space of principal engineering strains delineating the maximum safe strain and the strain perpendicular to it at the onset of necking. The FLD is considered a material limit that can not be exceeded by proportional straining. The "formability" of a sheet is a reflection of its FLD [5].

## 3. Results and Discussion

From the investigation by varying different parameters, the deformation results could be obviously distinguished. The parameters such as drawing ratio, die radius, friction, and formability has been observed which are discussed in successive sections.

### 3.1 The Effect of Drawing Ratio

The magnitude of the deformation of a part is usually characterized by the drawing ratio, which defines the ratio of the initial blank diameter to the inside diameter of the finished cup [2].The drawing ratio must not exceed a maximum limit of material in order to prevent cracking at the bottom of the cup [3]. The drawing ratio is calculated from the equation [3]:

$$\beta = \frac{d_0}{d_1}$$

where $d_0$ is the initial diameter of blank sheet and $d_1$ is the diameter of the punch.

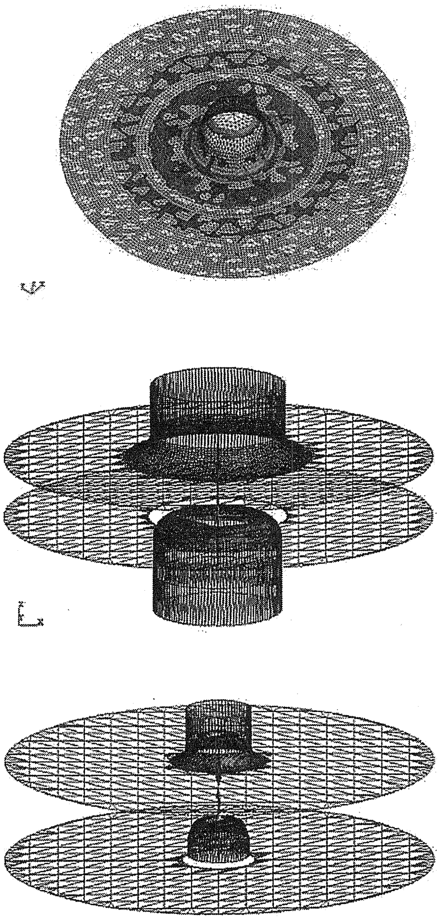

**Figure 3.** Punch and die setup for second drawing process and third redraw processes.

Considering the results, the simulation of smaller drawing ratio in Figure 4 has lower strain than the greater drawing ratio in Figure 5. The greater punch diameter would increase formability of metal while the excessive surface of the smaller punch diameter would resist the deformation of metal [3]. In Figure 4, the part shows a thickness of 1.16 mm. after the deformation.

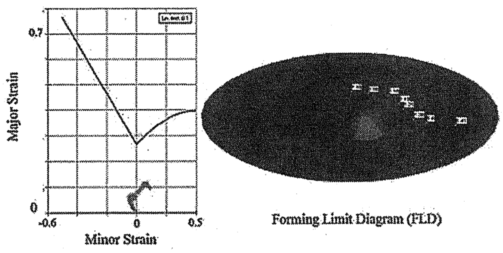


**Figure 4.** FLD for $\beta = 2.69$.

For large drawing ratio, the strain formed on part increase readily. In Figure 5, the part shows smaller thickness of workpiece 0.905 mm. after the deformation.

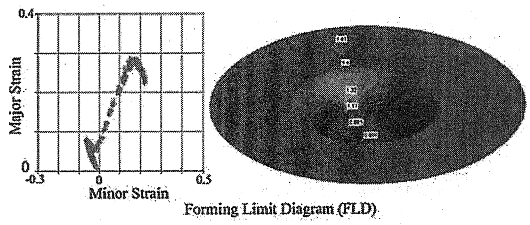


**Figure 5.** FLD for $\beta = 3.84$ and die radius 20 mm.

### 3.2 The Effect of Die Radius

During drawing the individual sheet is stretched or compressed until the internal moment in the cross section is equal to the externally applied bending moment on the die radius. In the region of the die radius, the sheet metal undergoes two fold bending. The sheet has bent to the radius at the die entrance and is straightened or unbent again at the exit of the die [2]. Considering the change of die radius parameters, an increase in the die radius would increase the ability of metal to flow according to the deformed shape. In comparison to FLD, the die radius of 20 mm as shown in Figure 5 causes higher strain than the die radius of 25 mm in Figure 6. Thus the sheet metal tends to deform more difficultly when the die radius was small.

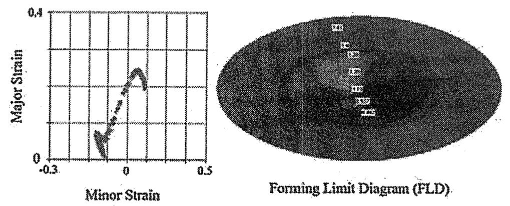


**Figure 6.** Die radius 25 mm.

### 3.3 The Effect of Friction

Existing friction normally causes radial stresses to increase, which is proportional to the blankholder pressure and the coefficient of friction, and is inversely proportional to the workpiece thickness [2]. The friction between die and flange and between blankholder and flange increases the drawing force [3]. Higher friction coefficients in Figure 7 show greater strain than lower friction coefficients in Figure 8. Thus higher friction requires greater drawing force.

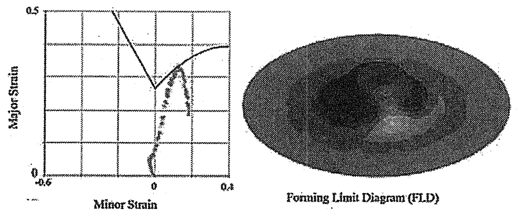


**Figure 7.** Friction coefficient of $\mu = 0.15$.

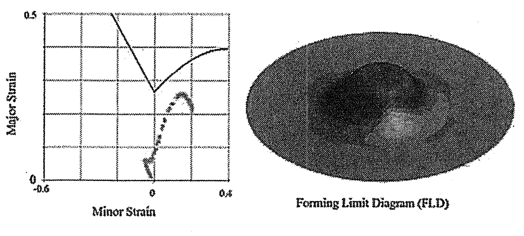


**Figure 8.** Friction coefficient of $\mu = 0.12$.

### 3.4 The Effect of Holes

The deformation is limited to the area under the punch. As the punch progresses, the material in this region is stretched and formed with superimposed bending over the rounded edges of punch and die. This deformation of material depends among other parameters on the drawing ratio, tool geometry, blankholder pressure and material properties [3]. In Figure 9, by addition of a hole the part can be formed with lower strain and has a thickness of 0.666 mm.

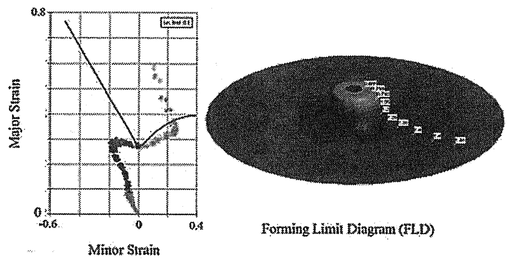


**Figure 9.** The redraw part with hole addition.

For the usual redraw part shown in Figure 10, a large strain formed with thickness of 0.455 mm. During the movement, the element near the hole experiences the deformation in a circumferential direction. Correspondingly the element is radially stretched and tangentially compressed which aids the deformation of the part [1].

### 3.5 The Effect of Formability

In the flange area, there are tangential compressive stresses that can cause wrinkles during buckling. Wrinkles can be avoided by using the blankholder pressured against the drawn component [3]. The pressure necessary to avoid wrinkles depends on the material, thickness, and drawing ratio [2][3]. In Figure 11 for first drawing, shadings of thickening areas caused by circumferential compressive stress, excessive compressed area and safe area for forming are shown.

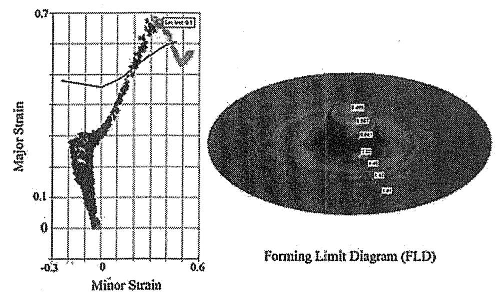


**Figure 10.** The usual redraw part.

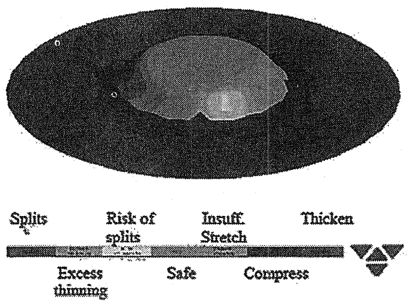


**Figure 11.** Second process for first draw.

In Figure 12 for the second redraw, shadings of thinning areas caused by radial tensile stress, and deformed areas reaching the material limit are shown.

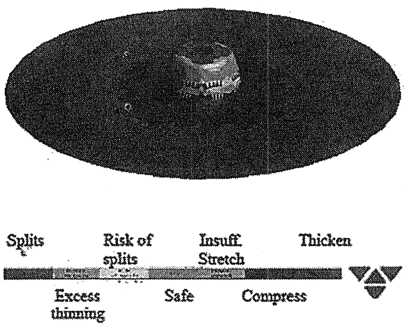


**Figure 12.** Third process for second redraw.

## 4. Conclusions

Deep drawing processes have significant roles in production in the automotive industry. Detailed information about the material behavior is very important in further development and understanding. The behaviors of material deformation depend on drawing ratio, tool geometry, blankholder pressure and mechanical properties of the material [6]. In this experiment, the large drawing ratio, small die radius, high value of friction coefficient, and complicated shape decrease formability of the material to flow during the drawing. Thus, it introduced strain hardening on the part which could result in rupture of material after several deformations [7]. Improvement of the production of body booster can be achieved by decreasing the drawing ratio of the first draw and introducing a hole in the second redraw process as shown in Figure 13.

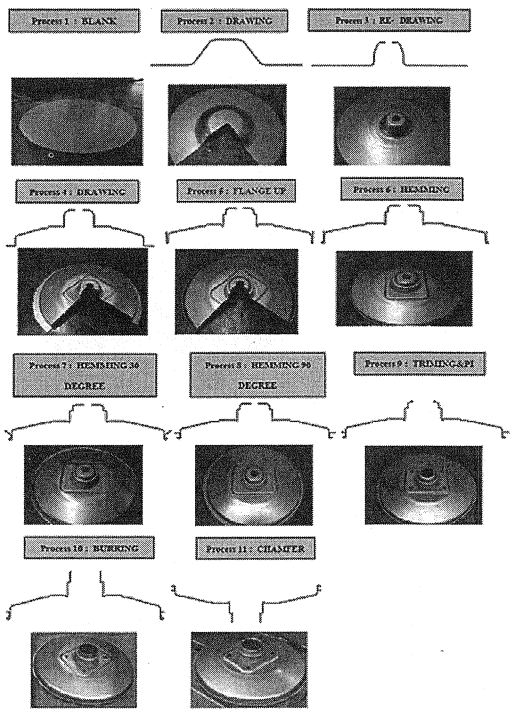

**Figure 13.** The modification of second and third production processes.

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