CHAPTER 6

RESULTS AND DISCUSSION

The objective of the research is to predict the strain distribution in the different sheet metal drawing operation and the failure modes to enable the designer to determine the process parameters to avoid such failure. A finite element procedure has been developed for carrying out the parametric analysis with axisymmetric conditions. The results are validated with the experiments.

6.1 EFFECT ON PUNCH LOAD

The load acting on the punch at different travel steps are simulated with the algorithm discussed in the preceding sections for the hemispherical and flat punch configurations. Stainless steel (304 grade) is used in the analysis of load. The punch load required to deform the metal are shown in Figures 6.1 and 6.2 for hemispherical and flat punch respectively. The punch load is compared with the experimental values for a travel of 25 mm and are shown in Table 6.1 and 6.2 for hemispherical and flat punch respectively.
FIGURE 6.1 VARIATION OF PUNCH LOAD WITH PUNCH TRAVEL

PUNCH HEMISPHERICAL PROFILE
BLANK MATERIAL: STAINLESS STEEL
THICKNESS: 0.8 mm
FIGURE 6.2 VARIATION OF PUNCH LOAD WITH PUNCH TRAVEL
## TABLE 6.1 PUNCH LOAD IN HEMISPHERICAL PUNCH DEEP DRAWING

<table>
<thead>
<tr>
<th>Material</th>
<th>Stainless Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness mm</td>
<td>0.8</td>
</tr>
<tr>
<td>Punch Travel</td>
<td>25 mm</td>
</tr>
<tr>
<td>Friction (μ)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Parameter</th>
<th>Analytical Result</th>
<th>Experimental Result</th>
<th>Published Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Punch Load (kN)</td>
<td>275</td>
<td>280</td>
<td>220</td>
</tr>
</tbody>
</table>
In the case of hemispherical punch, the load required to deform the metal is more than flat punch. The load required in the early stages of drawing is relatively less. The results are compared with the published values of Onate (1983), for hemispherical punch configuration. For the flat punch configuration, the load is compared with Albrecht P. Satlman (1985). The punch load is found to be good agreement with published values and analytical results for flat punch.

**TABLE 6.2 PUNCH LOAD IN FLAT PUNCH DEEP DRAWING**

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Parameter</th>
<th>Analytical Result</th>
<th>Experimental Result</th>
<th>Published Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Punch Load (kN)</td>
<td>138</td>
<td>138</td>
<td>137</td>
</tr>
</tbody>
</table>

Material : Stainless Steel  
Thickness mm : 0.8  
Punch Travel : 25 mm  
Friction (μ) : 0.2  

...
6.2 COMPARISON STRAIN DISTRIBUTION

The strain distribution in thickness, radial and circumferential direction are experimentally measured and compared with analytical results for three different materials – Aluminium, Stainless Steel and Deep draw quality steel.

6.2.1 Thickness Strain Distribution

The thickness strain distribution for Aluminium, Deep draw quality steel and Stainless Steel are shown in Figure 6.3 to 6.10. The thickness strain is positive near the flange portion indicating the thickening of the material between blank holder and die flange. The thickening of the material is observed in Aluminium, Deep draw quality steel and Stainless Steel. The thickness strain are in good agreement with the analytical results in the flange portion of the cup. The failure in the case of hemispherical punch is more pronounced near the punch region as evidenced by the thinning of the material. The thickness strain for the identical material and draw conditions, the hemispherical punch deep drawing gives maximum thinning effect in the full draw. The thickness strain variation pattern is more or less the same in the flange portion for all the materials with different thicknesses. In all the three materials the thinning is more pronounced in hemispherical punch configuration at full draw condition.

6.2.2 Radial Strain Distribution

The radial strain distribution for the different punch travels for the different materials are compared with the experimental values for the hemispherical and flat punch configurations. The results are shown in the
FIGURE 6.3 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.4 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.5 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.6 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.7 THICKNESS STRAIN DISTRIBUTION

- EXP. FULL 30 mm
- ANAL. FULL 30 mm
- ANAL. HALF 18 mm
- ANAL. HALF 6 mm

MATERIAL: STAINLESS STEEL
THICKNESS: 3.0 mm
H = 2 mm
FIGURE 6.8 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.9 THICKNESS STRAIN DISTRIBUTION
FIGURE 6.10 THICKNESS STRAIN DISTRIBUTION
Figures 6.11 to 6.18. The radial strain indicates the thinning of the material. As the punch travels more, the peak radial strain is shifting outward indicating the thickening of the flange. This is in conformity with published result of Keum (1990). The increase in the coefficient of friction will shift the peak radial strain outward indicating non-uniform metal flow, resulting in failure. The peak radial strain is higher in the hemispherical punch than flat punch in full draw conditions.

6.2.3 Circumferential Strain Distribution

The circumferential strain distribution for different punch travel steps are shown in Figure 6.19 to 6.26. The maximum strain occurs nearer to the die corner. The circumferential strain is negligible at the bottom of the cup and negative along the vertical wall indicating the metal flow resulting in the cup formation.

The strain distribution predicted by the present rigid-plastic Finite Element Method is in good agreement with experimental data over the flange portion for Stainless Steel, Deep draw quality steel and Aluminium. An improvement in the prediction of circumferential strain at the punch side is possible by assigning the proper friction coefficient between punch sheet interface. In this study, the practical difficulty lies in the assignment of reasonable value of friction coefficient because under the real sheet metal forming conditions, friction is difficult to measure. The frictional conditions may be change during deformation. It may be concluded that the rigid-plastic Finite Element Formulation can treat the sheet metal problem with efficiency and reasonable accuracy.
FIGURE 6.11 RADIAL STRAIN DISTRIBUTION
FIGURE 6.12 RADIAL STRAIN DISTRIBUTION
FIGURE 6.13 RADIAL STRAIN DISTRIBUTION
FIGURE 6.14 RADIAL STRAIN DISTRIBUTION
FIGURE 6.15 RADIAL STRAIN DISTRIBUTION
FIGURE 6.16 RADIAL STRAIN DISTRIBUTION
FIGURE 6.17 RADIAL STRAIN DISTRIBUTION
FIGURE 6.18 RADIAL STRAIN DISTRIBUTION
FIGURE 6.19 CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.20  CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.21 CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.22  CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.23 CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.24 CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.25 CIRCUMFERENTIAL STRAIN DISTRIBUTION
FIGURE 6.26  CIRCUMFERENTIAL STRAIN DISTRIBUTION