CHAPTER 2

MATERIAL BEHAVIOUR IN SHEET METAL FORMING

The behaviour of sheet metal during press forming has been investigated in all its aspects. It was experimentally studied for explaining the difference in the forming limit and for finding material factors governing the press formability of sheet metal. Some of the fundamental tests such as tensile test and hardness test were used in comparison with actual press performance as means of predicting the formability. Many industrial products are axi-symmetrical and unsymmetrical press forming. The number of geometrical factors increases abruptly, resulting in a considerable change in the role of sheet metal properties and press forming techniques. Comparison of press performance with data from (i) the tensile test (ii) Swift cup test (iii) deformation and fracture analysis rectangular shell was reported. These analyses deal with tearing off at the shell corner occurring towards the end of forming. The effect of deformation path on the forming limit was first discussed with respect to punch stretching and stretch flanging (Swift, 1951). Fracture limit analysis has been attempted on shallow and complex panels, covering the different aspects of drawing in relation to various geometrical defects resulting from unbalanced stress and strain distribution.

2.1 FACTORS AFFECTING MATERIAL BEHAVIOUR

The various factors governing the material behaviour in deep drawing process are shown in Figure 2.1. However, no factor can be related individually with deformation behaviour of sheet metals. Usually, tensile test values are used
FIGURE 2.1 FACTORS AFFECTING THE MATERIAL BEHAVIOUR IN PRESS FORMING
for assessing the deformation behaviour assuming that there is no change in stress-strain relation for various modes of deformation. The punch-stretchability of sheet metals is strongly affected by the work hardening coefficient (n value) governing the neck strain distribution. As the strain distribution depends on the geometry of forming and the forming limit is increased by the presence of deep drawability. The stretching depth and the work hardenability in relation to radial strain was reported by Yoshida (1966). Figure 2.2 illustrates the strain distribution at different stretching depth for various work hardening coefficients. In the round bottomed punch-stretching under low lubrication, the strain level in the centre area surrounded by the hoop fracture is lowered as the value of work hardening coefficient increases. This is because for the lower work hardening coefficient material, the centre area deforms more easily, being affected by stress gradient in the early stages of forming. Also, the effect of work hardening coefficient on punch work material stretchability is the greatest when the fracture is observed at the top of the round-bottomed punch under good lubrication. Deformation behaviour in flat bottom and over heavy regions is always in close relation with work-hardening coefficient value.

Yoshida, K. et al (1978) reported, in addition to the effect of work hardening value, the deformability of sheet metal after the onset of necking is also a factor affecting the punch-stretchability of material. The combined stretchability depends on the pure stretchability and deep drawability. It mainly depends on the n and r values.

The forming limit as measured by maximum stretching depth for different values of n or r with different shell geometries are shown in Figure 2.3. It is seen that the stretchability for different values of r, the steel sheets are fairly strong for circular shape, but likely to be affected by other forming geometries.
FIGURE 2.2 RADIAL STRAIN DISTRIBUTION FOR DIFFERENT WORK-HARDENING CHARACTERISTICS (WARWICK)
FIGURE 2.3 RELATION BETWEEN STRETCHING DEPTH AND 
$\eta$ OR $r$-VALUES FOR DIFFERENT FORMING GEOMETRY 
(YOSHIDA)
In the case of non-ferrous materials having the same r value, the stretchability is closely related to n value for all geometries of forming. The different in sensitivity to blank size between r and n value is due to the difference in mechanisms which affects the stretchability and deep drawability.

Yoshida, K. (1978) reported that fracture strength compared with the uniaxial tensile strength increased by increased r value in ferrous materials, while it decreased for non-ferrous material for different values of r. It is also established that the total effect of r value on the limiting draw ratio in a cylindrical cup test is considerably varied for different groups of sheet metal as shown in Figure 2.4. Yoshida K. et al (1978) reported that formability characteristics were strongly related to X value which is the ratio of the uniaxial to biaxial flow stress. Thus, the r value derived from the uniaxial tensile test is not a sufficient index to reveal all anisotropic natures of sheet metals under different modes of deformation.

It is clear that in punch-material stretching, the stress-strain relation characterized by n value is very important. The stress strain curves for the different materials and deformation modes differ considerably from each other. The n value derived from a small range of strain may be required for more accurate prediction of the instability point and punch-material stretching limit. Figure 2.5 shows the stress-strain curves for various materials. It is evident that the most important factors controlling the cup height are the strain hardening and strain rate sensitivity. Ghosh, A.K. (1977), had shown that the strain hardening coefficient controlled total elongation up to a maximum load and the strain rate sensitivity played important role in the post-uniform deformation.
FIGURE 2.4 RELATION BETWEEN LIMITING DRAWING RATIO AND \( r \)-VALUES (OKI. T)

- Fe
- Al
- Cu

Limiting Drawing Ratio vs. \( r \)
FIGURE 2.5 STRESS STRAIN CURVES FOR VARIOUS MATERIALS
ON THE ASSUMPTION OF ISOTROPY (YOSHIDA)
2.2 MECHANICS OF DEFORMATION

The material is deformed plastically to generate the shape of the derived product in the forming process. Metal flow is influenced mainly by

i) Tool geometry
ii) Frictional conditions
iii) Characteristics of stock material
iv) Thermal conditions existing in the deformation zone.

The mechanics of deformation like metal flow, strain and strain rate can be investigated by process modelling. The macro and microgeometry of the product like dimensions and surface finish, are influenced by the process variables. The processing conditions determine micro structural variations taking place during deformation.

2.3 EFFECT OF FRICTION

The drawability of the blank can be increased with high friction on the cylindrical surface of the punch. With the stretching of the wall, element on the wall would move upward relative to punch, causing a shear stress between the wall and punch so that the bottom of the wall does not experience full drawing force. The lower wall has not been work hardened as much as the region further up the wall. Thus, differential lubrication and roughend punches can be used to enhance the drawability. Granzow, W.G (1979), reported that a similar transfer of the drawing force to the sides of the punch may be aided by drawing into die cavity under high pressure, which forces the wall against the punch. With very
low friction there is increased thinning of the cup bottom and the failure site 
tends to shift downward into punch radius. In the flange portion, lubrication is 
beneficial since it reduces the work expended to overcome friction.

A review of published work on lubrication of sheet metal forming 
operations reported by Newnham J.A. (1970) indicates that the mechanical 
properties and boundary lubricity, work piece roughness, and deformation speed 
have greater influence on lubrication. The primary areas to be lubricated are 
blank-die and blank-hold ring interface, blank die corner interface, blank punch 
interface. When drawing starts the residual film at the blank die and blank-hold 
down ring will be wiped inwards by the motion of the blank. During this phase 
there will be some redistribution of load within the annular interface due to 
tendency of the blank to thicken as it is drawn inward. This will tend to thin out 
the film near the inner diameter. Analytical work has been reported based on foil 
theory for the lubrication application.

2.4 FAILURE MODES IN DEEP DRAWING

In deep drawing process, the maximum depth to which cylindrical cup can 
be drawn in a single stage is limited by the limiting draw ratio. The most 
common modes of failure in deep drawing are:

i) Wrinkling of the material on the flange of the cup

ii) Fracture of material in the pheriphery of punch profile radius.

The wrinkling is developed due to inadequate hold down pressure. In 
addition, beads are frequently added to the mating die and hold down surface. 
They may be provided either all around or only in the areas where wrinkling
would otherwise develop. Draw beads retard and control the flow of metal into
die. It is reported that on-set of wrinkling takes place when the plastic strain
increment reaches a critical value. The effect of mechanical properties on the
initiation, growth and buckling behaviour was reported by Yoshida K. et al
(1978). Narayanasamy R. et al (1993) have concluded that the percentage draw
deformation obtainable at the onset of wrinkling decreases with increasing blank
diameter for the tactrix die.