CHAPTER 1

INTRODUCTION

Among the most common manufacturing processes, sheet metal working has attained tremendous importance in modern mass production. The deep drawing and stretch forming processes account for a large proportion in metal forming operations. These processes require a thorough understanding of the deformation mechanics involved, for effective utilisation. In industrial usage, the sheet-metal forming refers to processing performed on sheets and requiring press operations involving dies, while deep drawing pertains to the family of drawing and redrawing operations to produce cups. Deep drawing covers a wide range of metal flow conditions. In all these conditions the major principal stress is tensile and atleast one surface of the deformed region is not supported by tools. The simplest process is the radial drawing in which a circular blank is drawn into straight, vertical, cylindrical cup. In cup drawing, one principal strain is tensile, the other is compressive and the change in thickness is relatively small. In a biaxial-stretching where two principal stresses are tensile, thinning is significant.

1.1 MECHANISM OF DEEP DRAWING PROCESS

The progressive stages of drawing a cylindrical cup is shown in Figure 1.1. The outer annular zone, X, is held under normal compression by the blank holder to prevent wrinkles which are likely to be induced in this region as the punch advances to pull the blank radially inwards towards the die opening. As the material from region X passes over the die, it is subjected to bending and
FIGURE 1.1 STAGES IN DEEP DRAWING
unbending under tension. The material initially in the region Y is bent and stretched either over the die profile or over the punch profile. The material which is initially over the flat face of punch, in region Z, is stretched under biaxial tensile force. The compressive hoop stress induces considerable increase in metal thickness, causing the flange to wrinkle or fold, if lateral hold down pressure is not applied. Between the fibres associated with drawing over the die and with stretching over the punch, there is a narrow band in zone Y, which escapes plastic bending and is subjected to predominantly simple tensile stress throughout the drawing process. This material stretches and thins to a lesser extent than the fibres on either side, giving a thicker band between two apparent necks. Figure 1.2, shows the variation in metal thickness for flat and hemispherical headed punches. Fracture of metal is likely to take place at one of the necks, usually at the one nearest to the punch head.

1.2 PROCESS CHARACTERIZATION

Predominant factors influencing sheet metal forming include sheet material characterization, tooling and equipment, deformation behaviour, friction and lubrication, product geometry and the properties of the materials.

1.2.1 Effect of Material Properties

For a given material composition, its material properties like flow stress and anisotropy are important variables which influence the forming. These properties affect the deformation behaviour in sheet metal drawing. The stretchability of sheet metal over the punch is its ability to elongate in the die cavity until the crack occurs on the blank. This property is strongly affected by the work hardening coefficient (n) governing the neck strain distribution.
FIGURE 1.2 VARIATION IN METAL THICKNESS FOR HEMISPHERICAL AND FLAT HEADED PUNCH.
Whitely R.L. (1960) showed experimentally that the limiting draw ratio depended on normal anisotropy (r) in sheet metal. With r-value greater than unity the flow stress in bi-axial tension is raised relatively to the flow stress under a tensile-compression system. Thus the material over the punch head is strengthened relative to the material in the flange and greater limiting draw ratio can be achieved. With a high r-value of the material the change in thickness of the flange as it is drawn towards die opening is less for a material with low r-value. The wall thickness of the resulting cup is more uniform. Thus for a given blank diameter a deeper cup will result from a high r-value material. Wilson F.W. et al (1965) reviewed the effect of anisotropy in deep drawing. The effect of the n-value and r-value on the limiting draw ratio has been reported by El-Sebaie M.G. and Mellor P.B. (1972).

1.2.2 Tooling and Equipment

The tooling variables include
i) Punch and die geometry
ii) Surface finish of tooling
iii) Stiffness
iv) Mechanical and thermal conditions.

The forming severity of the localized region is mainly governed by its geometry and ultimate ductility of sheet metal.

1.3 PUNCH PROFILE RADIUS

The geometry of the punch profile is of utmost importance since fracture usually occurs nearer to the punch radius. Chung S.Y. and Swift H.W. (1951)
reported that punch geometry in the punch fillet radius was a major variable in determining limiting draw ratio. The strain analysis in the neighbourhood of draw ratio indicate susceptibility to tearing at that region with practically no effects of strain outside its immediate vicinity. Empirical findings show that for $r_{\text{punch}} \leq 2t$, the cup is highly failure-prone due to tearing while for $r_{\text{punch}} \geq 10t$, stretching may be introduced (Lyman, T. 1969). The latter derives from the punch radius emulating a hemispherical headed punch and consequently, thinning becomes inevitable. In addition, it was reported that within the region $4t \leq r_{\text{punch}} \leq 10t$, the exact value did not significantly affect the limiting draw ratio. The effect of the punch profile and the thickness strain are shown in Figures 1.3 and 1.4. Thus, unless the shape of the cup actually requires the dimensions, it would be preferable to specify the punch radius in the range of 4t to 10t.

1.3.1 Radial Clearance

The clearance between the die throat and punch affects both the geometry of the cup and the flow regime. Geometry pertains to conicity and the roundness of the wall. Excessive clearance can cause “square” corners instead of a toroidal profile around die radius. Taper, aside from geometrical implications, produces susceptibility to puckering, since the tapered wall is not constrained by either die, punch or blankholder. Certain combinations of clearance and ensuing thickening will bring about ironing. At the boundary of ironing, insufficient clearance causes burnishing of metal.

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FIGURE 1.3 EFFECT OF PUNCH PROFILE ON THICKNESS STRAIN (HOBBS R.M.)
FIGURE 1.4 EFFECT OF DIE PROFILE ON THICKNESS STRAIN
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Johnson W. and Mellor P.B. (1976) recommended 30% clearance for a draw ratio and if ironing were permitted, 10% clearance would be satisfactory. Hand book of metal forming (Lange 1985) cites a general rule that a clearance of 7 to 15% of wall thickness will be satisfactory.

1.3.2 Die Profile Radius

The die radius depends on the size of the work piece and its thickness. A larger die radius is desired in order to lower the drawing load and to increase the limiting draw ratio. However, large radius reduces the contact area between blank holder and the flange and increases the tendency to form wrinkles in the region of die radius. The possibility of wrinkle formation is reduced if the die radius is reduced. Swift H.W. (1951) reported that the die radius less than 10 times blank thickness was satisfactory for most of the press working operations. If the die radius is decreased, it lowers the limiting draw ratio. Higher values of the die profile radius develop greater tendency to wrinkle.

According to Earry and Reed (1958) the variation in die fillet radius has the following major effects

i) The larger the bend radius, the greater the punch load and the plastic work done in bending.

ii) Small die radius may cause local failure in bending zone by increasing the work hardening tendency.

iii) The smaller die radius causes a heat build-up and weakening of the die material. This ultimately results faster erosion material making lubrication more difficult and galling more troublesome.
Thus, a the smaller die profile radius, will increase the peak punch load and lower the limiting draw ratio. Analytical modelling of plastic bending of the sheet over die radius was studied by Chung S.Y. and Swift H.W. (1951) and Salter R.A.C. (1977). Salter’s analysis assumed linear strain hardening and approximated the mean yield to Y. Assuming negligible changes in t, the additional stress due to plastic bending is

\[ \sigma_{\text{bending}} = \{ \frac{\bar{Y}}{t} \left[ 1 + \left( \frac{r_{\text{die}}}{r_{\text{blank}}} \right)^2 \right] \} + \left[ \sqrt{2.3 \left( \frac{t}{r_{\text{die}}} + \cdots \right)} \right] \]

Prediction of deep-drawability and start-of-flow conditions were attempted using the different methods of plasticity and various experimental approaches. Several models have been proposed to predict the deep drawability. Characterization and interdependencies between crystal structure, structural change during a draw, heat treatment and related defects were reported. Chung S.Y and Swift H.W. (1951) investigated and simplified the formulations to describe the principal phenomenon in deep drawing or stretching. Hosford W.F. (1983) used the notion of homogeneous work to predict an upper bound limit draw ratio which is mainly dependent on normal anisotropy.

A great deal of effort has been put into both experimental characterization and analytical modelling since Chung S.V. and Swift H.W. (1951). However, the basic metal flow pattern is neither sufficiently understood nor mathematically formalized.
1.3.3 Deformation Behaviour

In sheet metal forming, the material is deformed plastically to generate the shape of the desired product. The deformation behaviour of sheet metal operation is greatly influenced by the forming techniques. This may include deformation mode (type of forming), forming geometry, forming speed and forming limit.