CHAPTER 4

FUNDAMENTALS OF BENDING

4.1 INTRODUCTION

Sheet metal forming is one of the most common metal manufacturing processes that can be used to produce complex parts with a high degree of dimensional accuracy and increased mechanical properties, along with a good surface finish. Bending is defined as the plastic deformation of sheet metal along a straight line. Bending is a commonly used sheet metal shaping process in various sheet metal industrial products (Tekiner 2004). A bending operation is employed to fabricate parts such as braces, brackets, supports, hinges, angles, frames, channel and other non-symmetrical sheet metal parts which are used in automobiles, aircrafts, ships and various consumer products. There are two types of bending, ‘V’ bending and ‘U’ bending. The most common one is ‘V’ bending and this is subdivided into closed die bending and air bending (Tekiner 2004).

During the bending process, a force is applied to a sheet metal blank, causing it to bend at an angle and form the desired shape. The workpiece is initially bent in an elastic region. As the process continues, the workpiece is deformed by plastic deformation, thereby changing its shape. The material is stressed beyond the yield strength but below the ultimate tensile strength of the
material. The bending action results in both tension and compression in the sheet metal. The outer surface of the sheet undergoes tension and stretches to a greater length while the inner surface experiences compression and shortens. The tensile stresses and compressive stresses decrease towards the center of the sheet as shown in Figure 4.1. The neutral axis is the boundary line inside the sheet metal, along which tensile or compressive stresses are absent. As a result, the length of this axis remains constant (Farsi and Arezoo 2011). In bending analysis the deformation mode is considered as straight-line bending or plane-strain bending. The bent sheet can be divided into four deformation zones, namely: plastic, elastoplastic, elastic and rigid zones. Though a non-linear strain distribution of sheet thickness was considered by some researchers (Wang et al 1993), the shift in the neutral axis and reduction of the sheet thickness during bending were not considered. However, during bending, the position of the neutral axis shifts towards the inner radius of the sheet. Moreover in the plastic zone, where the sheet is in contact with the punch, thickness reduction takes place (Kim et al 2007).

![Figure 4.1 Stress distributions in bending](image)

Figure 4.1 Stress distributions in bending
4.2 PRESS BRAKE FORMING

Press brake forming is a process which employs a press brake for the bending operation. A press brake contains an upper tool called the punch and a lower tool called the die, between which the sheet metal is located. The sheet is carefully positioned over the die while the punch is lowered and forces the sheet to bend. The bend angle achieved is determined by the depth upto which the sheet is forced into the die by the punch. This depth is precisely controlled to achieve the desired bend. A press brake is commonly used for forming long narrow components and for applications in small batch-part-manufacturing. Low carbon steels, killed steels, High strength low alloy (HSLA) steels, stainless steel, aluminium and brass are some of the materials formed in a press brake. The fundamental advantage of the press brake lies in its flexibility to accommodate different part sizes, shapes and materials.

4.3 AIR BENDING PROCESS

The two most common methods in press brake forming are bottoming and air bending. In bottoming or closed die bending, the punch forces the sheet completely into the die and at the end of the bending process, the punch, the sheet and the die are in solid contact. The major limitation in this method is that more tools are required for a certain work range as the angle of punch and die must be accurately matched for any specific bend.

In air bending, the sheet surface is touched by the tools in three locations: the punch surface and two die corners. The punch does not force the
sheet completely up to the bottom of the die cavity, leaving space or air underneath, as shown in Figure 4.2. Air bending is commonly used in automotive stamping and fabrication industries (Kim et al. 2007).

Figure 4.2 Schematic diagram of air bending

Advantages of air bending process

- In air bending different bend angles can be produced by adjusting the punch travel alone into the die, without the need for tool changes, and this makes the technique more flexible than closed die bending.
- Since the punch does not force the sheet against the die, the force necessary to form the parts is small and hence much less press tonnage is required compared to closed die bending.
- Air bending can allow a degree of over bending necessary to compensate for springback.
Limitations

- A precise control of the punch stroke is necessary to obtain the desired bend angle.
- Springback in an air bending process is large in the absence of bottoming.

4.4 SPRINGBACK

During bending the load is applied to bend the part in the expected shape. The bending tool bends the metal into a certain angle with a given bend radius. After bending, when the tool is removed, there is a dimensional change of the bent part as shown in Figure 4.3, widening the angle and increasing the radius referred to as springback.

\[
\begin{align*}
R_i & \quad \text{Bend radius before springback} \\
R_f & \quad \text{Bend radius after springback} \\
\theta_i & \quad \text{Bending angle before springback} \\
\theta_f & \quad \text{Bending angle after springback}
\end{align*}
\]

Figure 4.3 Springback in bending process
The stress-strain plot shown in Figure 4.4 illustrates the springback phenomenon. In a bending process, during unloading, the total strain on the work part is reduced due to elastic recovery. Elastic recovery is the release of the elastic strain and redistribution of residual stresses along the thickness direction, thus inducing springback (Dieter 1988).

![Stress-Strain diagram and springback](image)

**Figure 4.4 Stress-Strain diagram and springback**

### 4.4.1 Mechanism of Springback

According to the plastic deformation theory, the material is generally divided into two zones: the elastic and the plastic zones. The elastic property tries to maintain the material in the initial shape, whereas the plastic property tries to retain the material in the deformed shape. In a sheet metal bending process, the bending load increases until the material exceeds the elastic limit and enters the
plastic deformation state. The outer surface of the material is subjected to the tensile stress, which propagates inward towards the neutral plane. The inner surface of the material is subjected to the compressive stress and it propagates inward towards the neutral plane. This means that the metal near the neutral axis has been stressed to values below the elastic limit. This creates a narrow elastic band on both sides of the neutral axis, as shown in Figure 4.5. The metal far away from the neutral axis may be stressed beyond the yield stress and has been plastically or permanently deformed. When the bending load is removed at the end of the bending stroke, the elastic band tries to return to the original condition but is restricted by the plastic zone. When the elastic and plastic zones reach equilibrium, it results in a partial elastic recovery which is called as springback (Semiatin 2006). Thus, the workpiece tries to springback and the bent part slightly opens out.

Figure 4.5 Elastic band in the bent part
4.4.2 Factors Influencing Springback

Springback could be influenced by many variables such as material properties (yield strength, Young’s modulus, strain hardening exponent, strength coefficient), sheet metal geometry (thickness, width), tooling dimensions (punch radius, die radius, die opening) and process parameters (punch travel, punch velocity). Springback is a formidable problem that affects the quality of the bent part and may cause problems in the assembly. It cannot be completely eliminated, so at least it must be compensated. In bending practice, springback is usually compensated by over bending the part for a small radius of curvature than desired so that after springback, the part has the required radius. Another method is to coin the bent area by subjecting it to high localised compressive stresses, between the tip of the punch and the die surface, known as bottoming the punch. Because springback decreases as yield stress decreases, all other parameters being the same, bending may also be carried out at elevated temperatures to reduce springback (Kalpakjian 1997).

4.4.3 Springback Ratio

The amount of springback can be defined either by a non-dimensional springback factor \( K_s \), which is the ratio between the final bending angle \( \theta_f \) and the loading bending angle \( \theta_i \), or by a springback angle \( \Delta \theta \).

\[
\text{Springback ratio } (K_s) = \frac{\theta_f}{\theta_i} \tag{4.1}
\]

\[
\text{Springback angle } (\Delta \theta) = \theta_i - \theta_f \tag{4.2}
\]
Angle and radius are intimately related to each other and hence springback can be estimated approximately by Equation (4.3). This equation has been used as a simplified reference approximation for springback computation (Kalpakjian, 1997) assuming the hypothesis of constant thickness and arc length.

\[
\text{Springback ratio } \frac{R_i}{R_f} = 4 \left( \frac{R_i \sigma_y}{E t} \right)^3 - 3 \left( \frac{R_i \sigma_y}{E t} \right) + 1
\]  

(4.3)

where,

- \( R_i \) - Radius in the loading state
- \( R_f \) - Final radius
- \( t \) - Thickness
- \( \sigma_y \) - Yielding stress
- \( E \) - Young’s modulus.

### 4.5 BEND FORCE

Bend force is the force required to cause a sheet metal to bend at an angle and form the desired shape. Bend force depends on the maximum external bending moment which consists of two elements: (i) the bending moment due to bend force and punch travel (ii) the additional moment to overcome the friction around the die shoulders.

Bend force is influenced by sheet metal properties (thickness, tensile strength, strain hardening exponent, strength coefficient), the tool parameters (punch radius, die radius, die width), the process parameters (punch displacement,
bending angle) (Wang et al 1993). Bend force can be estimated by assuming the process as a simple beam bending.

The maximum bend force $P$ can be expressed as (Kalpakjian, 1997)

$$P = \frac{k(\sigma_u)Lt^2}{W}$$  \hspace{1cm} (4.4)

where,

- $k$ - Die opening factor (1.2 - 1.33)
- $\sigma_u$ - Ultimate tensile strength
- $L$ - Length of the bend
- $t$ - Sheet thickness
- $W$ - Die opening

4.6 CONCLUSION

In this chapter, the fundamentals of bending are detailed. Press brake forming, the air bending process, its advantages and disadvantages are reviewed. Springback, the mechanism of springback and the factors influencing springback are explained. Bend force and the factors influencing bend force are presented.