Chapter 15: Fundamentals of Metal Forming

Reference: DeGarmo’s Materials and Processes in Manufacturing
15.1 Introduction

- Deformation processes have been designed to exploit the plasticity of engineering materials.
- Plasticity is the ability of a material to flow as a solid without deterioration of properties.
- Deformation processes require a large amount of force.
- Processes include bulk flow, simple shearing, or compound bending.
States of Stress

TABLE 15-1 Classification of States of Stress

1. Simple uniaxial tension
2. Biaxial tension
3. Triaxial tension
4. Biaxial tension and compression
5. Uniaxial compression
6. Biaxial compression
7. Biaxial compression, tension
8. Triaxial compression
9. Pure shear
10. Simple shear with triaxial compression
11. Biaxial shear with triaxial compression
15.2 Forming Processes: Independent Variables

- Forming processes consist of independent and dependent variables.
- Independent variables are the aspects of the processes that the engineer or operator has direct control:
  - Starting material
  - Starting geometry of the workpiece
  - Tool or die geometry
  - Lubrication
  - Starting temperature
  - Speed of operation
  - Amount of deformation
### TABLE 15-2  Classification of Some Forming Operations

<table>
<thead>
<tr>
<th>Process</th>
<th>Schematic Diagram</th>
<th>State of Stress in Main Part During Forming&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling</td>
<td><img src="image1.png" alt="Rolling Diagram" /></td>
<td>7</td>
</tr>
<tr>
<td>Forging</td>
<td><img src="image2.png" alt="Forging Diagram" /></td>
<td>9</td>
</tr>
<tr>
<td>Extrusion</td>
<td><img src="image3.png" alt="Extrusion Diagram" /></td>
<td>9</td>
</tr>
<tr>
<td>Shear spinning</td>
<td><img src="image4.png" alt="Shear Sonning Diagram" /></td>
<td>12</td>
</tr>
</tbody>
</table>
Forming Operations

- Tube spinning
- Swaging or kneading
- Deep drawing
- Wire and tube drawing

In flange of blank, 5
In wall of cup, 1
Forming Operations

- **Stretching**
  - 2

- **Straight bending**
  - At bend, 2 and 7

- **Contoured flanging**
  - At outer flange, 6
  - At bend, 2 and 7
  - At outer flange, 1
  - At bend, 2 and 7

*Numbers correspond to those in parentheses in Table 15-1.*
15.3 Dependent Variables

- Dependent variables are those that are determined by the independent variable selection
  - Force or power requirements
  - Material properties of the product
  - Exit or final temperature
  - Surface finish and precision
  - Nature of the material flow
15.4 Independent-Dependent Relationships

- Independent variables- control is direct and immediate
- Dependent variables- control is entirely indirect
  - Determined by the process
  - If a dependent variable needs to be controlled, the designer must select the proper independent variable that changes the dependent variable
Independent-Dependent Relationships

Information on the interdependence of independent and dependent variables can be learned in three ways

- Experience
- Experiment
- Process modeling

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Links</th>
<th>Dependent variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting material</td>
<td>-Experience-</td>
<td>Force or power requirements</td>
</tr>
<tr>
<td>Starting geometry</td>
<td>-Experiment-</td>
<td>Product properties</td>
</tr>
<tr>
<td>Tool geometry</td>
<td></td>
<td>Exit temperature</td>
</tr>
<tr>
<td>Lubrication</td>
<td>-Modeling-</td>
<td>Surface finish</td>
</tr>
<tr>
<td>Starting temperature</td>
<td></td>
<td>Dimensional precision</td>
</tr>
<tr>
<td>Speed of deformation</td>
<td></td>
<td>Material flow details</td>
</tr>
<tr>
<td>Amount of deformation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 15-1 Schematic representation of a metalforming system showing independent variables, dependent variables, and the various means of linking the two.
15.5 Process Modeling

- Simulations are created using finite element modeling
- Models can predict how a material will respond to a rolling process, fill a forging die, flow through an extrusion die, or solidify in a casting
- Heat treatments can be simulation
- Costly trial and error development cycles can be eliminated
15.6 General Parameters

- Material being deformed must be characterized
  - Strength or resistance for deformation
  - Conditions at different temperatures
  - Formability limits
  - Reaction to lubricants
- Speed of deformation and its effects
- Speed-sensitive materials- more energy is required to produce the same results
15.7 Friction and Lubrication Under Metalworking Conditions

- **High forces and pressures** are required to deform a material.
- For some processes, 50% of the energy is spent in overcoming friction.
- **Changes in lubrication** can alter material flow, create or eliminate defects, alter surface finish and dimensional precision, and modify product properties.
- Production rates, tool design, tool wear, and process optimization depend on the ability to determine and control friction.
Friction Conditions

- Metalforming friction differs from the friction encountered in mechanical devices
- For light, elastic loads, friction is proportional to the applied pressure
  - $\mu$ is the coefficient of friction
- At high pressures, friction is related to the strength of the weaker material

Figure 15-2 The effect of contact pressure on the frictional resistance between two surfaces.
Friction

- Friction is resistance to sliding along an interface

- Resistance can be attributed to:
  - Abrasion (เป็นรอย)
  - Adhesion (ไม่ยั้งหรือติดแน่น)

- Resistance is proportional to the strength of the weaker material and the contact area
Surface Deterioration

- Surface wear is related to friction
- Wear on the workpiece is not objectionable, but wear on the tooling is
- Tooling wear is economically costly and can impact dimensional precision
- Tolerance control can be lost
- Tool wear can impact the surface finish
Lubrication

- Key to success in many metalforming operations
- Primarily selected to reduce friction and tool wear, but may be used as a thermal barrier, coolant, or corrosion retardant

Other factors
- Ease of removal, lack of toxicity, odor, flammability, reactivity, temperature, velocity, wetting characteristics
15.8 Temperature Concerns

- Workpiece temperature can be one of the most important process variables

- In general, an increase in temperature is related to a decrease in strength, increase in ductility, and decrease in the rate of strain hardening

- Hot working

- Cold working

- Warm working
There are three temperature ranges in metal forming processes:

<table>
<thead>
<tr>
<th>Category</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Working</td>
<td>$\leq 0.3 \ T_m$</td>
</tr>
<tr>
<td>Warm Working</td>
<td>$0.3 \ T_m - 0.5 \ T_m$</td>
</tr>
<tr>
<td>Hot Working</td>
<td>$0.5 \ T_m - 0.75 \ T_m$</td>
</tr>
</tbody>
</table>

*Where* $T_m$ is the melting point of the metal
Cold Working

- Performed at room temperature or slightly above
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required

*These operations are near net shape or net shape processes*
Advantages of Cold Working

Significant advantages of cold forming compared to hot working

- Better accuracy, meaning closer tolerances
- Better surface finish
- Strain hardening increases strength and hardness
- Contamination problems are minimized
- No heating of work required
Disadvantages of Cold Working

There are certain disadvantages or limitations associated with cold working

- Higher forces are required to initiate and complete the deformation
- Heavier and more powerful equipment and stronger tooling are required.
- Surfaces of starting workpiece must be free of scale and dirt.
- Ductility and strain hardening limit the amount of forming that can be done
  - In some operations, metal must be annealed to allow further deformation
  - In other cases, metal is simply not ductile enough to be cold worked
Warm Working

- Performed at temperatures above room temperature but below recrystallization temperature.

- Dividing line between cold working and warm working often expressed in terms of melting point:

  \[0.3T_m, \text{ where } T_m = \text{melting point for metal}\]
Advantages of Warm Working

The lower strength and strain hardening as well as higher ductility of the metal at the intermediate temperatures provide warm working the following advantages over cold working:

- Lower forces and power than in cold working
- More intricate work geometries possible
- Need for annealing may be reduced or eliminated
Hot Working

- Deformation at temperatures above *recrystallization temperature*
  
- Recrystallization temperature = about one-half of melting point
  
- In practice, hot working usually performed somewhat above 0.5\(T_m\)
  
- Metal continues to soften as temperature increases above 0.5\(T_m\), enhancing advantage of hot working above this level
  
- Capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working
Advantages of Hot Working

• Workpart shape can be significantly altered
• Lower forces and power required
• Metals that usually fracture in cold working can be hot formed
• Strength properties of product are generally isotropic
• No strengthening of part occurs from work hardening
  – Advantageous in cases when part is to be subsequently processed by cold forming
Disadvantages of Hot Working

- Lower dimensional accuracy
- Higher total energy required (due to the thermal energy to heat the workpiece)
- Work surface oxidation (scale), poorer surface finish
- Shorter tool life