Chapter 15: Fundamentals of Metal Forming

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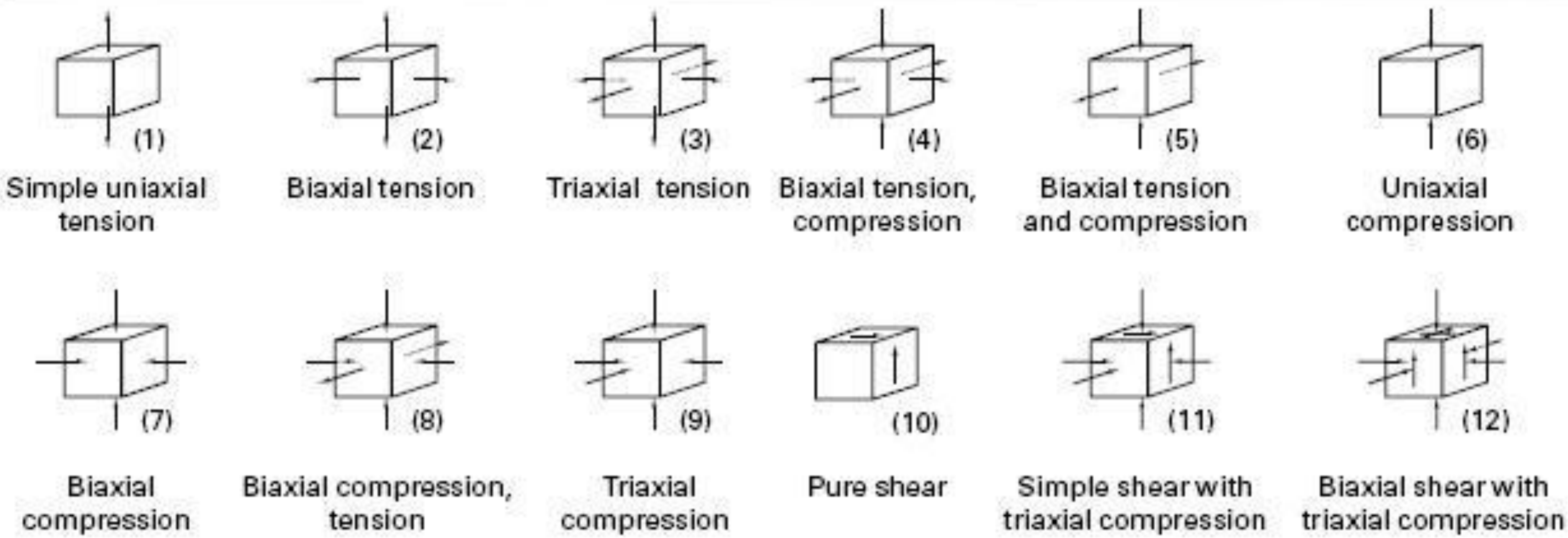
Reference: DeGarmo’s Materials and Processes in Manufacturing

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

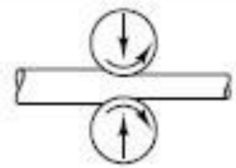
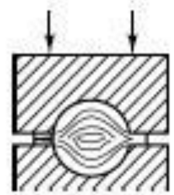
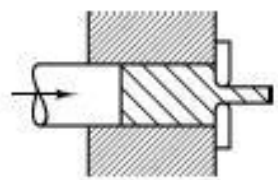
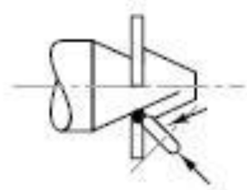


15.2 Forming Processes: Independent Variables

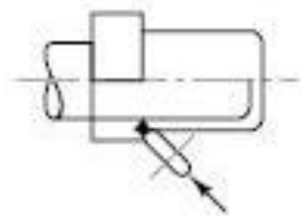
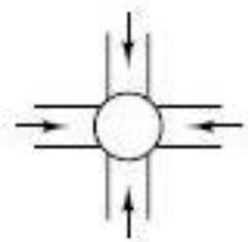
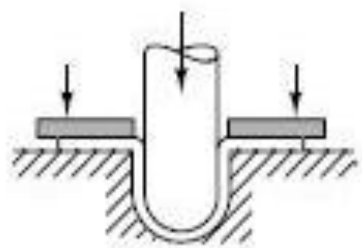
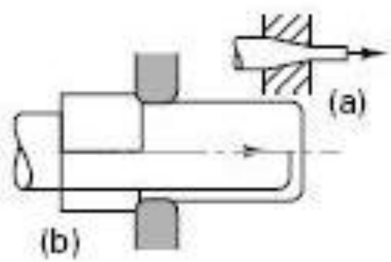
- Forming processes consist of independent and dependent variables
- Independent variables are the aspects of the processes that the engineer or operator has direct control
  - Starting material
  - Starting geometry of the workpiece
  - Tool or die geometry
  - Lubrication
  - Starting temperature
  - Speed of operation
  - Amount of deformation

Forming Operations

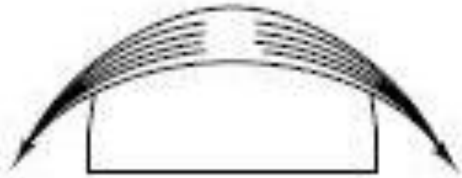
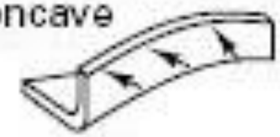
TABLE 15-2 Classification of Some Forming Operations

Process	Schematic Diagram	State of Stress in Main Part During Forming[a]
Rolling		7
Forging		9
Extrusion		9
Shear spinning		12

Forming Operations

Tube spinning		9
Swaging or kneading		7
Deep drawing		In flange of blank, 5 In wall of cup, 1
Wire and tube drawing		8

Forming Operations

Stretching		2
Straight bending		At bend, 2 and 7
Contoured flanging	(a) Convex 	At outer flange, 6 At bend, 2 and 7
	(a) Concave 	At outer flange, 1 At bend, 2 and 7

[a] 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

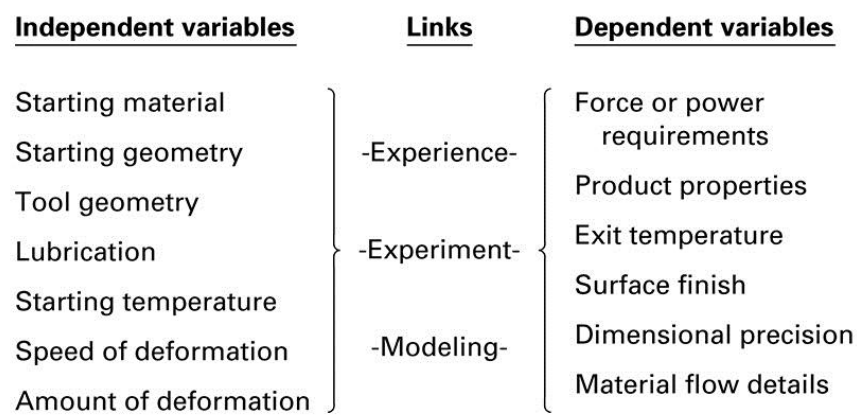


Figure 15-1 Schematic representation of a metalforming system showing independent variables, dependent variables, and the various means of linking the two.

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
  - μ is the coefficient of friction
- At high pressures, friction is related to the strength of the weaker material

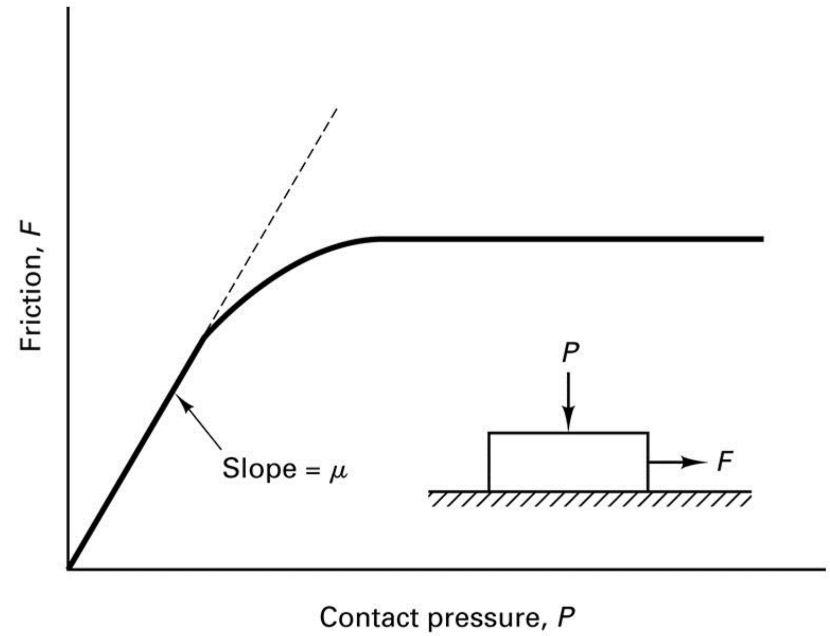


Figure 15-2 The effect of contact pressure on the frictional resistance between two surfaces.

Friction

- Friction is resistance to sliding along an interface
- Resistance can be attributed to:
  - Abrasion(เป็นรอย)
  - Adhesion(ไม่ขยับหรือติดแน่น)
- 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

Temperature Ranges Metal Forming

- There are three temperature ranges in metal forming processes:

Category	Temperature Range
Cold Working	$\leq 0.3\ T_m$
Warm Working	$0.3\ T_m – 0.5\ T_m$
Hot Working	$0.5\ T_m – 0.75\ T_m$

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:

  $0.3T_m$, where T_m = 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*Tm*
- Metal continues to soften as temperature increases above 0.5*Tm*, 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