Fundamental of forming process

4-1 introduction
Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces. Deformation results from the use of a tool, usually called a die in metal forming, which applies stresses. Stresses applied to plastically deform the metal are usually compressive, stretch, bend, or shear stresses to the metal. To be successfully formed, a metal must possess certain properties. Desirable properties include low yield strength and high ductility. Metal forming processes can be classified into two basic categories: bulk deformation processes and sheet metalworking, and these two categories contain many processes as shown in figure 4.1

Bulk Deformation Processes
Bulk deformation processes are generally characterized by significant deformations and massive shape changes, and the surface area-to-volume of the work is relatively small. The term bulk describes the work parts that have this low area to-volume ratio. Figure 4-2 shows some common bulk deformation processes.

Sheet Metalworking
Sheet metalworking processes are forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is high; thus, this ratio is a useful means to distinguish bulk deformation from sheet metal processes. Pressworking is the term often applied to sheet metal operations because the machines used to perform these operations are presses. Sheet metal operations are always performed as cold working processes and are usually accomplished using a set of tools called a punch and die. The basic sheet metal operations are sketched in Figure 4-3.
The behavior of metals during forming can be obtained from the stress–strain curve. The typical stress–strain curve for most metals is divided into an elastic region and a plastic region. In metal forming, the plastic region is of primary interest because the material is plastically and permanently deformed in these processes. The typical stress–strain relationship for a metal exhibits elasticity below the yield point and strain hardening above it. In the plastic region, the metal’s behavior is expressed by the equation:

\[ \sigma = K \varepsilon^n \]  

Where \( K \) = the strength coefficient, MPa (lb/in²); and \( n \) is the strain-hardening exponent. The stress \( \sigma \) and strain \( \varepsilon \) in the equation are true stress and true strain.

**Flow Stress** The flow curve describes the stress–strain relationship in the region in which metal forming takes place. It indicates the flow stress of the metal the strength property that determines forces and power required to accomplish a particular forming operation. For most metals at room temperature, the stress–strain plot of Figure 4.4 indicates that as the metal is deformed, its strength increases due to strain hardening. The stress required to continue deformation must be increased to match this increase in strength. Flow stress is defined as the instantaneous value of stress required to continue deforming the material to keep the metal “flowing.” It is the yield strength of the metal as a function of strain, which can be expressed:

\[ Y_f = K \varepsilon^n \]  

Where \( Y_f \) = flow stress MPa (lb/in²).

**Average Flow Stress** The average flow stress (also called the mean flow stress) is the average value of stress over the stress–strain curve from the beginning of strain to the final (maximum) value that occurs during deformation. The value is illustrated in the stress–strain plot of Figure 4.4. The average flow stress is determined by integrating the flow curve equation, Eq. (4.2), between zero and the final strain value defining the range of interest. This yields the equation:

\[ Y_f = \frac{K \varepsilon^n}{1+n} \]

Where \( Y_f \) = average flow stress, MPa (lb/in²); and \( \varepsilon \) = maximum strain value during the deformation process.
Temperature in metal forming

For any metal, the values of K and n depend on temperature. Strength and strain hardening are both reduced at higher temperatures. These property changes are important because they result in lower forces and power during forming. In addition, ductility is increased at higher temperatures, which allows greater plastic deformation of the work metal.

Cold Working (also known as cold forming) is metal forming performed at room temperature to $0.3T_m$. Significant advantages of cold forming compared to hot working are:

1. Greater accuracy, meaning closer tolerances can be achieved
2. Better surface finish;
3. Higher strength and hardness of the part due to strain hardening
4. Grain flow during deformation provides the opportunity for desirable directional properties to be obtained in the resulting product;
5. No heating of the work is required, which saves on furnace and fuel costs and permits higher production rates.

There are certain disadvantages or limitations associated with cold forming operations:

1. Higher forces and power are required to perform the operation.
2. Care must be taken to ensure that the surfaces of the starting workpiece are free of scale and dirt.
3. Ductility and strain hardening of the work metal limit the amount of forming that can be done to the part.

Warm working the term warm working is applied to this second temperature range. The dividing line between cold working and warm working is often expressed in terms of the melting point for the metal. The dividing line is usually taken between $(0.3T_m-0.5T_m)$, where $T_m$ is the melting point for the particular metal. The advantages of warm working over cold working are:

1. Lower forces and power.
2. More intricate work geometries possible.
3. Need for annealing may be reduced or eliminated.

Hot Working Hot working (also called hot forming) involves deformation at temperatures above the recrystallization temperature. The recrystallization temperature for a given metal is about one-half of its melting points on the absolute scale. The range of hot working it’s about $(0.5T_m-0.75T_m)$.

The advantages of the hot working are:

1. Shape of the workpart can be significantly altered
2. Lower forces and power are required to deform the metal
3. Metals that usually fracture in cold working can be hot formed
strength properties are generally isotropic because of the absence of the oriented grain structure typically created in cold working (5) no strengthening of the part occurs from work hardening

**Disadvantages** of hot working include:

1. Lower dimensional accuracy.
2. Higher total energy required (due to the thermal energy to heat the workpiece).
3. Work surface oxidation (scale).
4. Poorer surface finish.
5. Shorter tool life.

**Isothermal forming** refers to forming operations that are carried out in such a way as to eliminate surface cooling and the resulting thermal gradients in the workpart. It is accomplished by preheating the tools that come in contact with the part to the same temperature as the work metal. The variations in temperature and strength in different regions of the workpiece cause irregular flow in metal during deformation, leading to high residual stresses and possible surface cracking.

**4-4 Friction and lubricants**

Friction in metal forming arises because of the close contact between the tool and work surfaces and the high pressures that drive the surfaces together in these operations. In most metal forming processes, friction is undesirable for the following reasons:

1. Metal flow in the work is retarded, causing residual stresses and sometimes defect.
2. Forces and power to perform the operation are increased.
3. Tool wear can lead to loss of dimensional accuracy.

If the coefficient of friction becomes large enough, a condition known as sticking occurs. Sticking in metalworking (also called sticking friction) is the tendency for the two surfaces in relative motion to adhere to each other rather than slide.

**Considerations in choosing an appropriate metalworking lubricant include:**

1. Type of forming process (rolling, forging, sheet metal drawing, and so on).
2. Whether used in hot working or cold working.
3. Work material.
4. Chemical reactivity with the tool and work metals and Toxicity
5. Ease of application.
6. Flammability.
7. Cost.

**Lubricants used for cold working** operations include mineral oils, fats and fatty oils, water-based emulsions, soaps. **Hot working** is sometimes performed dry for certain operations and materials (e.g., hot rolling of steel and extrusion of aluminum). When lubricants are used in hot working, they include mineral oils, graphite, and glass.