Module 8. Bulk Deformation of Metals

MECH 392, UBC, Instructor: Ahmad Mohammadpanah

Bulk deformation processes in metalworking defines as change in the geometry of parts whose initial form is bulk rather than sheet. The initial shapes are usually billet (square cross-section) or slab (rectangular cross-section). These processes include Rolling, Drawing, Extrusion, and Forging. Here is some demo of these operations:

Bulk deformation processes can be a cold or a hot operation. Cold operation is used when the shape change is small. This process increases the strength of a part through strain hardening. Hot working operations can achieve significant change in the shape of work part.

There are several advantages of bulk deformation metalworking processes over alternative methods of making the same parts, such as machining or casting; these advantages are: - raw material saving, - ideal grain orientation for the specific application - strengthen

Module Objective:

In this module you will learn:

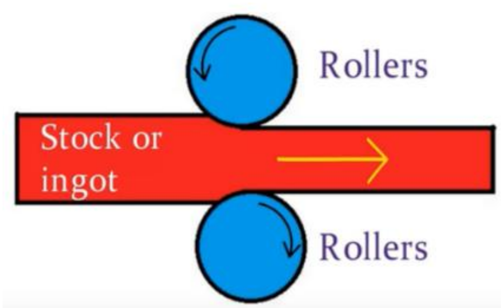
1. The principles and applications of main bulk deformation processes in metalworking, which includes: Rolling, Extrusion, Drawing, and Forging.
2. How to apply basic engineering analysis to estimate the required force and other important parameters in bulk deformation processes.

The outline of this module:

1. **Rolling**
    1.1. Fundamental of rolling
    1.2. Thread rolling
    1.3. Ring rolling
2. **Extrusion**
3. **Drawing**
4. **Forging**
    4.1. Open-die forging
    4.2. Impression forging
    4.3. Flashless forging

1. Rolling

In this process the thickness of the workpiece is reduced, or the shape of cross section changed by compressive forces exerted by two or more rollers. Most rolling operations are done by hot working. For example, for steel the temperature for rolling is about 1200 C. A secondary operation and further flattening of hot -rolled plate is done by cold rolling. Cold rolling strengthens the metal and improve the surface of sheet metal.

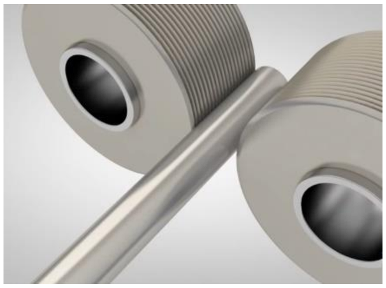


Hot-rolled plates are used in ships, bridges, boilers, heavy machines, tubes and pipes. Cold-rolled products are usually used for automobiles.

Other closely processes related to rolling process are thread rolling and ring rolling:

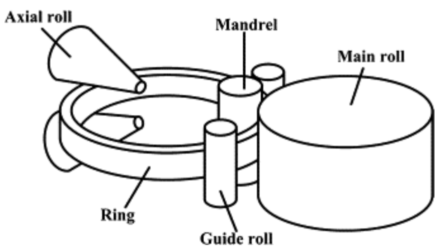
1.1.Thread Rolling:

It is the most important commercial process for mass production of bolts and screws. This process is usually a cold-working process.



1.2. Ring Rolling:

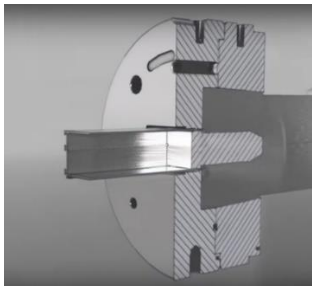
In this process a thick-walled ring of smaller diameter is rolled into a thin-walled ring of larger diameter. The process is usually a hot-working process. Applications include ball and roller bearings, steel tires for railroad wheels, rings for pipes, and pressure vessels.



2. Extrusion:

In this process, the work metal is forced through a die opening to produce a desired cross-sectional shape. In this process, a variety of cross-sectional shapes, with fairly close tolerance is possible. The process has little or no waste material and enhanced grain structure and strength can be achieved.

Here is the process animation:

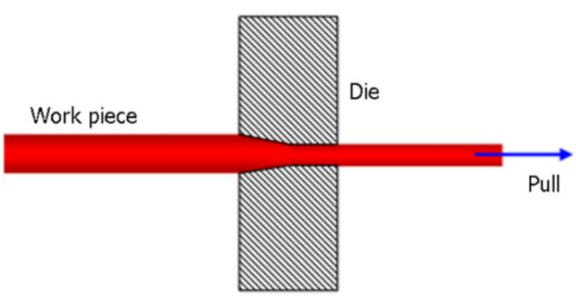


Here the actual process is explained:

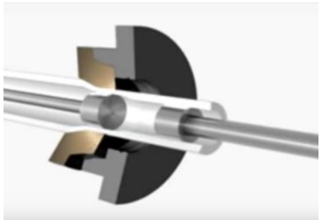
And, here you can find out where the Aluminum extrusion profiles come from:

3. Drawing:

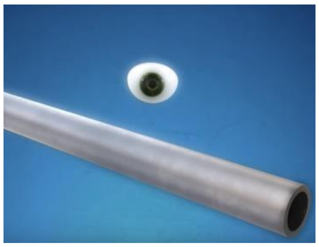
In this process, the cross section of a bar, rod, or wire is reduced by pulling it through a die opening. This process is very similar to extrusion, except the work metal is pulled through the die in drawing, whereas it is pushed in extrusion.



Here is a drawing process animation:



Here all the steps to produce Steel tubes are explained:



4. Forging

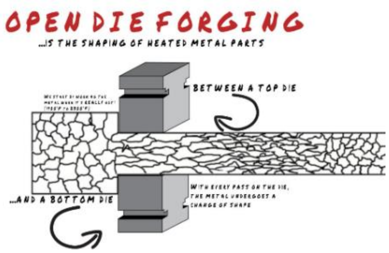
In this process, the workpiece is compressed and formed between two dies, either by impact or gradual pressure. It is an important industrial process for making a variety of high-strength components for cars, such as engine crankshafts and gears and in aerospace industry, such as aircraft structural parts, jet engine turbine parts, and many other applications.

Most forging operations are performed hot to increase ductility of the workpiece during the process. The forging machine that applies an impact load is called forging hammer, and the machine that applies gradual load is called a forging press.

There are three main types of forging operations, *i*. ***Open-die***, *ii*. ***Impression-die***, and *iii*. ***Flashless forgings***

4.1. Open-die forging

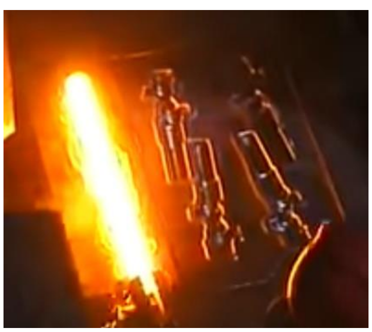
This operation is also known as ***upset forging***. In this operation the workpiece is often rotated in steps to affect the desired shape changed. It yields an optimum combination of strength, toughness, and fatigue resistance due to favorable grain flow and grain orientation and contoured. Here it is explained why:



Her is a demo of open-die forging;

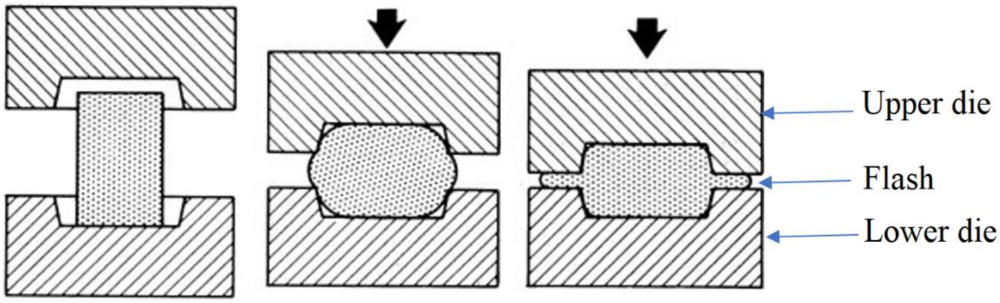
4.2.Impression-die forging

This operation is also known as ***closed-die forging***. It is performed with a negative die.

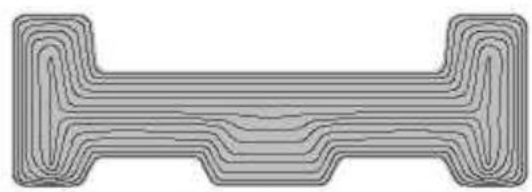


The following figure shows a schematic of three steps in this process. First placing the workpiece in the die, then partial compression, and final die closure, causing flash to form in gap between die plates. This flash must be trimmed in a subsequent operation. The flash serves as an important function. As the flash begins to form, friction resists flow of material, also this thin flash cools quickly against the die plates, thereby constrains the bulk

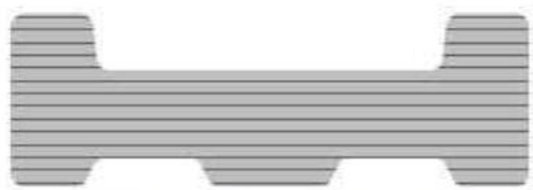
<u>of the work material to remain in the die cavity and increases the compression pressures on the part, thus forcing the material to fill the intricate details of the die cavity</u>.



This process is not capable of close tolerance parts, and machining is often required for precision finishing, such as holes, thread, and surfaces that mate with other components. The main advantages of forging over machining are **higher production rates**, **less metal waste**, **greater strength**, and **favorable grain orientation** of the metal which results in better **fatigue resistance**. Forged components for mining, energy and oil-field equipment outperform castings thanks to the enhanced performance that optimizing grain flow provides. A comparison of the grain flow in forging and machining is illustrated in following figure.



Part by hot forging, higher strength,
Grain flow follows the part contour,
durable under repeated stresses,



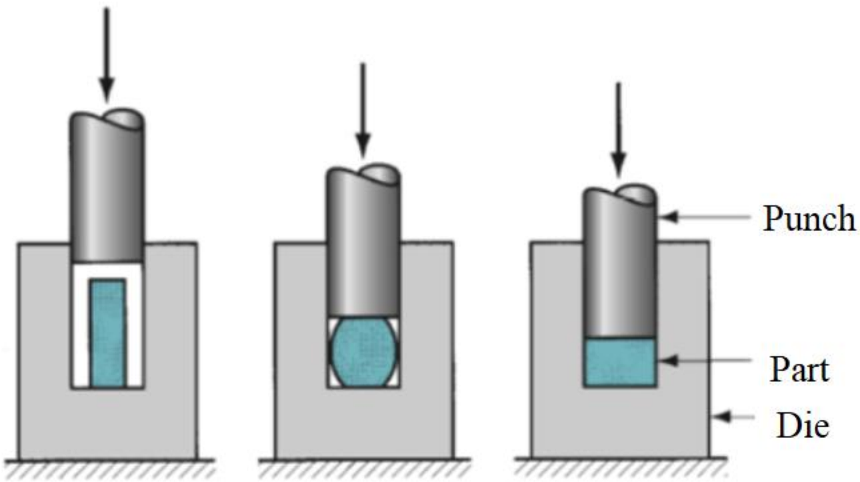
Same part by machining, lower strength

Study more on how forging affects grain structure from this link:

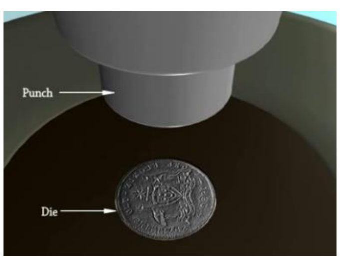
http://www.dropforging.net/how-does-forging-affect-grain-structure.html

4.3.Flashless forging

Flashless forging, also known as ***precision forging,*** is very similar to closed-die forging, but there is a distinction between closed-die forging (above) and true close-die forging here, known as flashless forging. In this operation, the raw workpiece is completely contained within the die cavity during compression, and no flash is formed. The process sequence is shown below. In this process, the work volume must be calculated thoroughly, so that, it equals the space in the die cavity. If the starting raw blank is too large, excessive pressure can cause damage to the die press, and if too small, we will not get the desired final shape. This process best fits for small, simple, and symmetrical geometries, with materials such as aluminum and magnesium alloys.

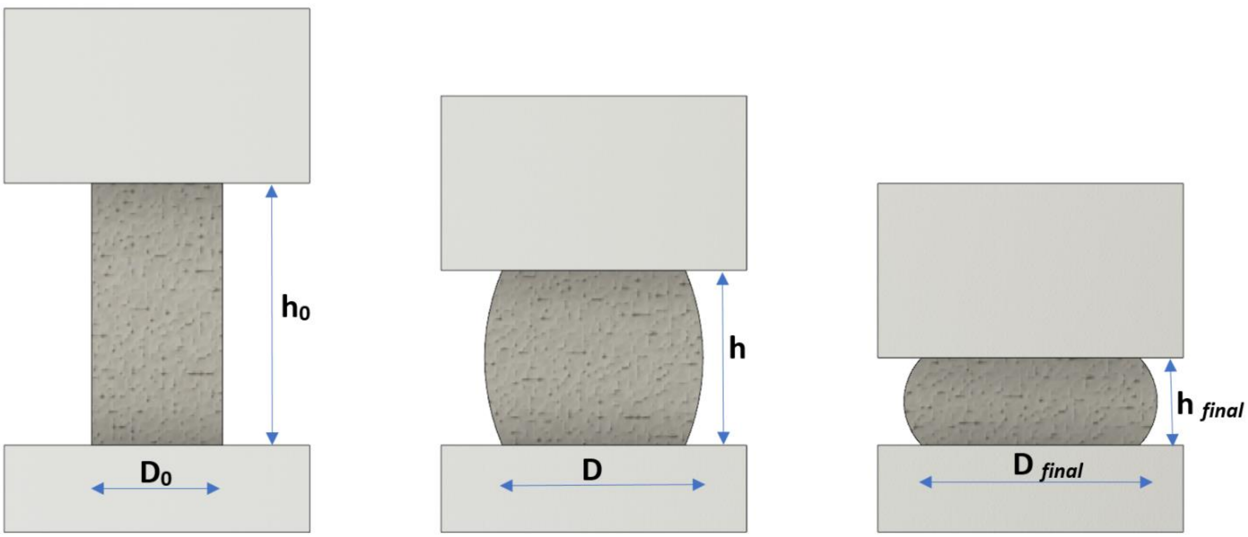


Coining is an example of flashless forging. In this process, the fine details in the die are impressed into the top and bottom surfaces of a small disk.



Although normally there is little flow of metal in flashless forging of small components, the pressure required is very high. For example, we need about 10,000 N for forging a 10mm steel ball. Check this video to find out how balls in ball bearings are made by flashless forging:

Engineering Analysis of Forging:



Estimating the required force to perform forging is essential. Consider a block of height h_0. The force required to compress it to height h can be estimated by:

$$F = K_f.K.\epsilon^n.A$$

Where A is the cross-section area of the workpiece, K is the strength coefficient of material, and n is the strain hardening exponent. Values of K and n are different for different materials and are calculated experimentally (*more details during class lecture*). The following table shows K and n for some metals (Reference: *Groover, M. P., Fundamentals of Modern Manufacturing*).

No.	Material	Strength Coefficient K (MPa)	Strain Hardening n Exponent
1	Aluminum, pure, annealed	175	0.2
2	Aluminum alloy, annealed	240	0.15
3	Aluminum alloy, heat treated	400	0.1
4	Copper alloy, Brass	700	0.35
5	Steel, low C	500	0.25
6	Steel high C	850	0.15
7	Steel alloy	700	0.15
8	Stainless steel	1200	0.4

ϵ is the true strain and can be computed by:

$$\epsilon = \ln \frac{h_0}{h_1}$$

K_f is the ***forging shape factor*** and can be calculated by:

In open-die forging:

$$K_f = 1 + \frac{0.4\mu D}{h}$$

μ is the friction coefficient between the workpiece and the die surface.

In impression-die the shape factor is (empirical values):

Part Shape	K_f
Simple shape	6
Complex Shape	8
Very Complex Shape	10

In flashless-die the shape factor is (empirical values):

Part Shape	K_f
Coining	6
Complex Shape	8

Engineering analysis of "rolling" will be covered in class lecture…