MCG 1100 - Introduction to Mechanical Engineering

Dissection Lab 2 - Manufacturing Processes

(prepared by M. Munro and W. Hallett)

In this lab, some common manufacturing processes, mostly for metals, will be presented. You will learn how the components that you deal with in this course are made, and how to identify the manufacturing processes used to produce a particular piece. You will fill in the blanks on the pages that follow with your notes taken during class.

1. Production of Basic Shapes

Manufacturing begins with raw materials. Metals are produced in simple forms such as plates, sheets, bars, tubes and structural shapes (such as angles, channels and I-beams).

Rolling

The process for producing flat sheets and plates is rolling: the piece is shaped by passing through suitably shaped rolls. This may be done hot (hot rolling, with the material at red or yellow heat) or at room temperature (cold rolling). Round and square bars and structural steel shapes such as angles, I-beams, H-columns, channels and railway rails are also produced this way.

Hot-rolled material is usually fairly soft, because it has been annealed during production. Characteristics of hot-rolled metal are:

- a fairly rough dark surface, because it oxidizes during rolling
- surface often has a few loose flakes ("mill scale").

Structural steel shapes are hot-rolled.

Cold-rolled material is generally much harder because of the cold working it has undergone. Characteristics of cold-rolled metal are:

- a fairly smooth (but not shiny) surface
- harder than the equivalent hot-rolled metal.

Cold rolling is usually only used to produce simple shapes (plates and bars), not structural shapes.

Pipes and Tubes

Pipes, tubes and other hollow sections may be produced by a number of processes. Tubes were originally made by forming sheet material into a tube and welding the seam, and this process is still used for some grades of steel pipe and tube today. Seamless tubing (*i.e.* without a welded joint) can be made by hot rolling material over a mandrel (a rod which forms the interior of the tube). Some pipe with a heavier wall thickness, such as cast iron soil pipe, is made by centrifugal casting, in which the molten metal is introduced into a rotating mould.

Extrusion

This process involves pushing or pulling metal through a suitably shaped die to produce a continuous shape. This may be done hot or cold. Quite complex shapes, such as aluminium window frame sections, can be made by extrusion, and the process can also be used for plastics.

Wire-drawing

Wire is produced by wire-drawing: a rod (originally produced by rolling) is pulled through a series of progressively smaller dies until it is reduced to the correct size. Since this process involves a great deal of plastic deformation, making the metal harder, the material must often be annealed between stages.

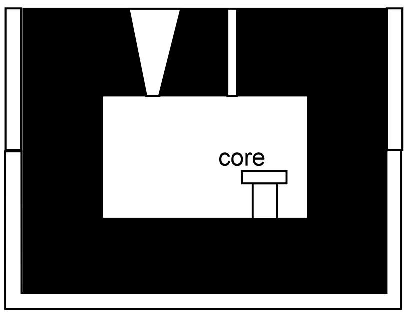
Reference: *Marks' Standard Handbook* p. 13-11 - 13-16

2. Casting

A casting process fills a mould with a liquid material which then solidifies to form the desired part. There are several different types.

2.1 Expendable Mould Casting

An expendable mould process is one in which the mould is only used for one casting. After the casting is made, the mould becomes unusable and a new mould must be made for every casting.



The most common of these processes is **sand casting**:

- mould is in two parts, made of hard packed sand
- mould made by packing sand around a **pattern** (a duplicate of the part to be produced)
- holes made to pour the metal in (the **gate**), and let gases out (**vents**).
- internal holes and cavities cast using inserts called **cores**, made of sand with a binder added.

How to identify components made by sand casting:

- surface rough (because of sand) - machining of casting needed to produce smooth surfaces

- parting line (joint between mould halves)

- no small details or very thin sections

Very complex internal shapes, such as the cooling and exhaust passages in engine cylinder blocks, can be made with sand casting using cores. Sand casting cannot be used to produce very small or very thin objects or precision parts.

Reference: pages 13-3 - 13-9 in *Mark's Standard Handbook*

2.2 Permanent Mould Casting

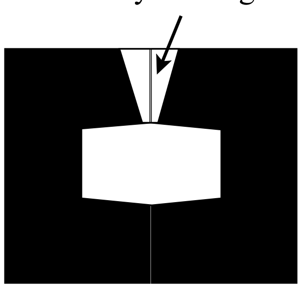
"Permanent" refers to the fact that the mould can be used for a large number of castings. As in sand casting, the mould has two parts which are put together to form the mould cavity and separated to release the finished part. The mould may also have movable parts to produce simple holes or undercuts; however, they cannot produce complex internal cavities such as can be formed by the use of cores in sand casting.

Description of Processes

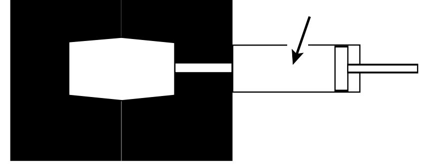
- **gravity casting**:
  - metal is simply poured into the mould under gravity as in sand casting
  - metal cannot flow long distances or fill small cross-sections
  - products do not have fine details or thin sections.

- **die casting**:
  - metal is forced into the mould under high pressure
  - metal can flow long distances, fill very small cross-sections
  - products have smooth surfaces, fine details, thin sections

Gravity Casting



Die Casting



Since the mould used for permanent mould casting is usually of steel, the metals used must have melting points substantially below those of steel or cast iron; for this reason, permanent mould and die casting are almost never used for iron steel. On the next page is a table of the melting temperatures of some common metals.

Metals which can be cast by permanent mould casting (gravity or die-casting):
- non-ferrous metals: aluminium, brass, bronze, zinc alloy, magnesium

Metals which **cannot** be cast by permanent mould casting (gravity or die-casting):
- steel, cast iron or stainless steel - temperatures too high

Melting Temperatures of Common Metals

Note: these are approximate values only - exact values depend on alloy composition. In addition, most alloys go through a range of temperatures when melting, and do not have a single melting temperature.

Metal	Melting point (°C)	Metal	Melting point (°C)
Iron (pure)	1540	Aluminium (and alloys)	500 - 600
Steel	1400 - 1550	Zinc alloys for die casting	380 - 430
Cast iron	1200 - 1400	Tin	232
Copper	1100	Lead	328
Brass, bronze	900 - 1050	Soft solder (tin and lead alloys)	180 - 230

Sources: Machinery's Handbook, Marks' Standard Handbook for Mechanical Engineers

How to identify components made by permanent mold and die casting:

BOTH - *smooth surfaces (steel moulds have machined surfaces)*

- *parting line (joint between mould halves) very thin*

- *non-ferrous metal*

- *can have small details*

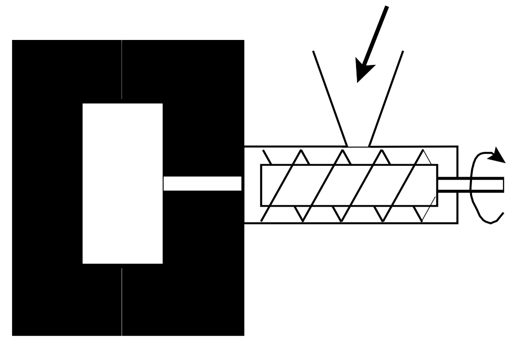
BUT Gravity casting - *simple geometry, short distance for metal to flow*

Die casting - *complex geometries, metal can flow a long distance, thinner cross sections and finer details than in gravity casting, internal holes*

None of the metal moulding processes can produce parts of high precision. Surfaces mating with other parts or requiring high precision are typically subjected to machining operations after casting.

Reference: pages 13-3 - 13-9 in *Mark's Standard Handbook*

2.3 Injection Moulding (Plastics)



Injection moulding is a permanent mould casting process used for plastics. As in die casting, the molten plastic is forced into the mould at high pressure. Injection moulding is the most common manufacturing process used for plastics, and almost all plastic pieces produced in large volumes are made this way.

Injection moulding and die casting are similar processes, but injection moulding refers only to plastics, and die casting only to metals.

How to identify components made by injection moulding:

- made of meltable plastics (thermoplastics)

- smooth surface finish

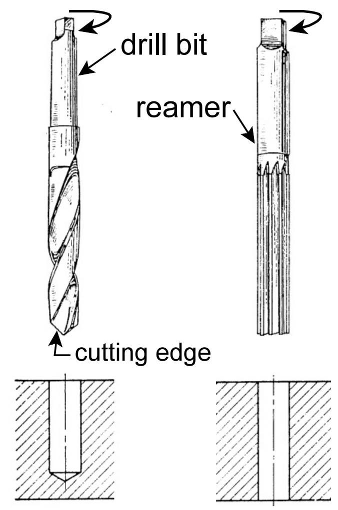
- complex shapes, fine details and thin cross sections possible

3. Machining

Machining operations use cutting tools to remove material from rough shapes such as castings, bars or plates. They are used to produce surfaces with a smooth surface finish and a high degree of precision. Ordinary machining operations can typically achieve a precision of ± 0.001" (± 0.02 mm). A very common manufacturing sequence for metals uses a casting process to produce a rough shape, which is then machined to produce high precision surfaces where necessary.

3.1 Drilling

Small holes (up to 50 mm diameter) are produced by drilling, in which a rotating drill bit is pushed into the workpiece. The cutting edges of the bit are at the tip; the spiral grooves (“flutes”) remove the chips. The drill bit may be held in a hand-held drill, but for precise work it is held in a drill press, a machine which ensures that the drill moves in a straight line. A drilled hole is not always very accurate; if a high degree of accuracy is required, the hole is finished with a reamer, which is fed through the drilled hole and removes a very small amount of metal.

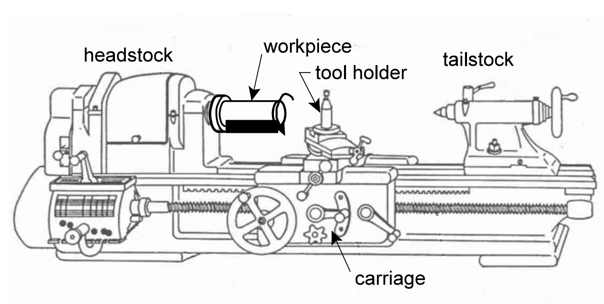


(French & Vierck, *Engineering Drawing*, McGraw-Hill 1947.)

Larger holes begin as drilled holes and are then enlarged by boring - see below under Lathe Operations.

3.2 Lathe Operations

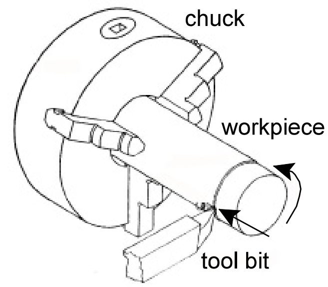
In a lathe the workpiece is rotated at a constant speed and cutting tools are moved along the workpiece to create cylindrical parts. The lathe has three main parts: a headstock, which rotates the workpiece, a tailstock, which can be used to support one end of the workpiece or to hold tools such as drills, and a carriage, which holds the cutting tool and moves it in two or three coordinate directions. The main operations are turning, facing, drilling and boring (note: **there is no such word as “lathing”**). External and internal screw threads may also be cut.



(Begeman, *Manufacturing Processes*, Wiley 1957)

Reference: *Marks' Standard Handbook*, p. 13-56 - 13-61.

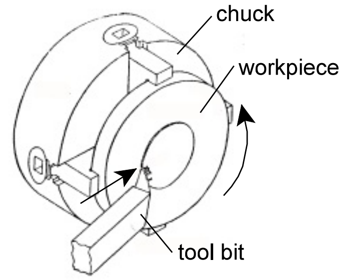
Turning



The most basic lathe operation is turning, used to produce cylindrical shapes. The cutting tool is moved parallel to the axis of the rotating workpiece, tracing a cylindrical path. More complex shapes can be produced by moving the tool bit along paths of varying radius.

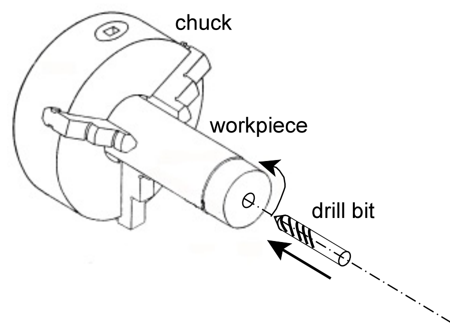
Long workpieces must be supported at the end by the tailstock, and sometimes by other fixtures as well. Turning cannot be used to produce very long thin pieces which are too flexible to support properly.

Facing



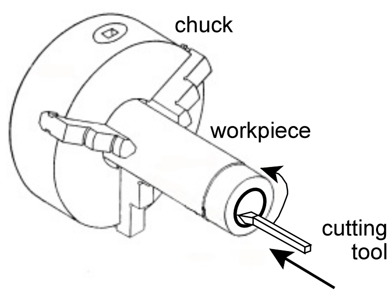
Facing is used to produce a flat surface on the end ("face") of a workpiece. The cutting tool is moved at right angles to the axis of the rotating workpiece, and in doing so traces a plane exactly normal to the axis. Again, the tool path may be varied to produce more complex shapes.

Drilling



A hole may be drilled and reamed in the centre of the end of a workpiece by a drill bit mounted in the tailstock. The drill bit does not rotate, but is pushed into the work as the work rotates.

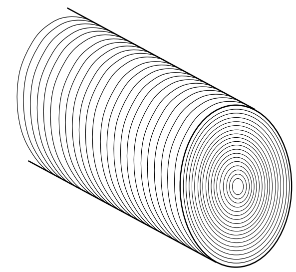
Boring



Larger holes or holes of more complex shape are produced by boring, in which a drilled hole is enlarged using a cutting tool fed in from the end. This operation is essentially the same as turning except that it happens inside the hole.

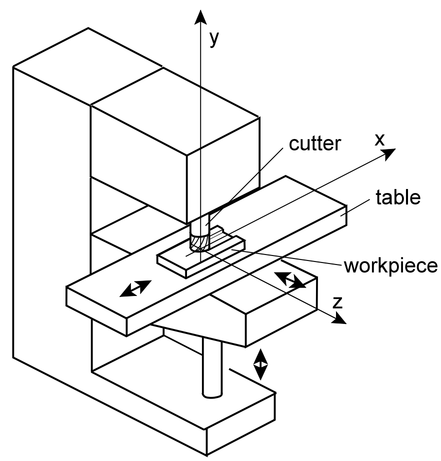
How to tell if a piece has been machined in a lathe:
- cylindrical surface:
  - *fine grooves (tool marks) run around circumference of piece*
  - *turning is only way to produce machined cylindrical surface*

- flat surface:
  - *tool marks form a series of circles all centred on the same point*



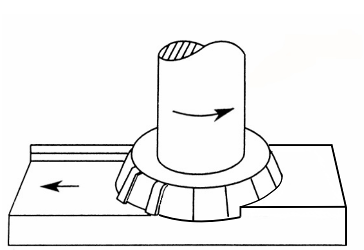
Machining marks from turning (left) and facing (right) on a cylindrical piece

3.3 Milling Operations

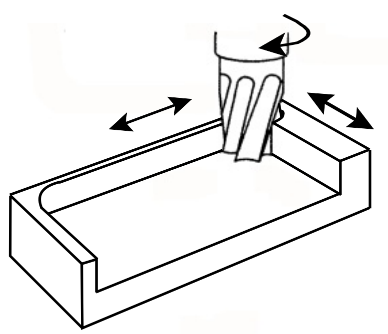


A milling machine (also called a "mill") uses rotating cutters to machine surfaces. The workpiece is moved past the cutter in three coordinate directions; in some cases the workpiece may also be rotated. In most modern machines, the cutter rotates around a vertical axis ("vertical mill"), but some have a horizontal spindle instead. The rotating cutter usually has cutting teeth both on the end and the side. Most have a cylindrical shape, but some are shaped to cut a particular cross-section ("form cutters"). In addition to regular milling cutters of different shapes, milling machines may use cutting heads containing a number of individual cutting tools (called "inserts") assembled in one unit. These are often used for boring and facing operations, particularly in automated milling machines.

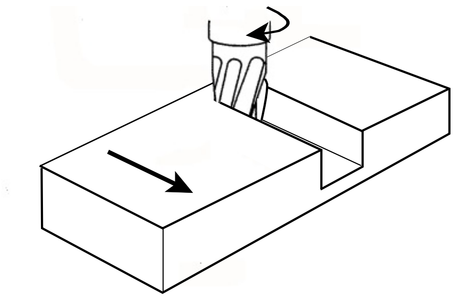
Reference: *Marks' Standard Handbook*, p. 13-62 - 13-63.



Milling a flat surface ("face milling")

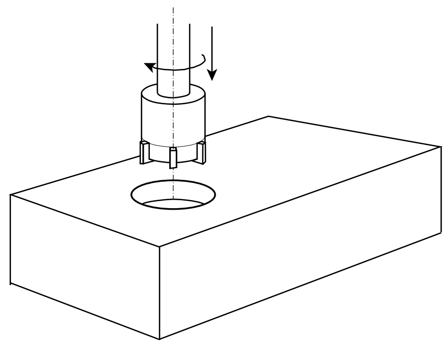


Milling pockets and corners



Cutting a slot with an end mill

Cutti[redacted]
a for[redacted]



Boring or drilling in a milling machine

Mach[redacted]he side
(top) [redacted]milling
cutte[redacted] of the
arrow[redacted]

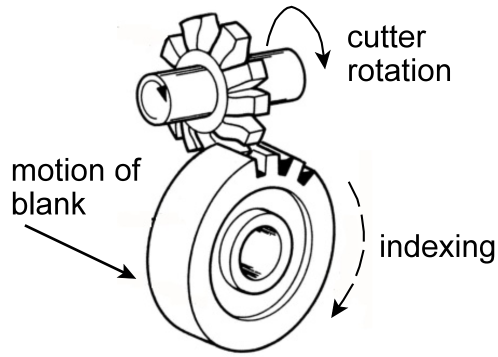
How to identify components that have been milled:

- end of the cutter produces *machining marks that are a se*[redacted]*, all of same radius*

- side of the cutter produces *machining marks that are straig*[redacted]*direction of cutter motion*

Milling machines can also use drills to produce small ho[redacted]to produce larger bores. These operations are similar to those in the lathe, exce[redacted]achine the work is stationary and the drill or boring head rotates.

Gear Teeth Cutting (Form Cutting) in the Milling Machine



Gears may be cut in a milling machine using a form cutter, which is a milling cutter made in the shape of the gear tooth. The gear blank moves past the cutter to cut each tooth (sketch), and is then advanced ("indexed") through the correct angle for the next tooth.

A faster process is **hobbing**, which cuts the teeth with a rotating screw-like cutter while the gear blank rotates. Another process is **shaping**, which uses a reciprocating cutter to cut each tooth. All these leave similar machining marks, and it is difficult to tell which process has been used. Inexpensive (but less precise) gears may also be made by die casting (for metals) and injection moulding (plastics).

3.4 Other Machining Operations

(a) Precision Grinding

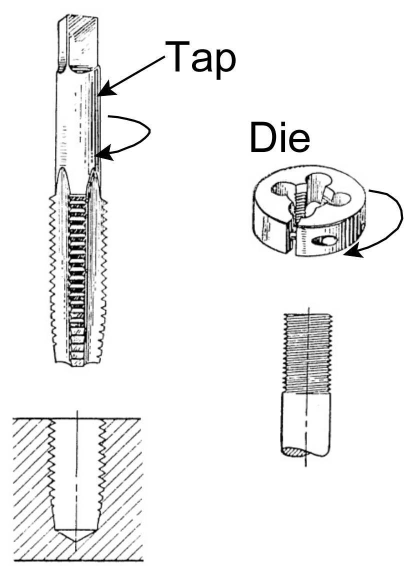
Pieces which require an even smoother surface finish and/or higher degree of precision than is possible with machining are finished by precision grinding after machining. Grinding operations parallel those carried out on the lathe and milling machine, except that a grinding wheel rotating at high speed replaces the cutting tool. Only very small amounts of material are removed. Grinding is also used to finish and sharpen milling cutters and lathe tool bits. A special process called centreless grinding is used to finish high precision shafts and other cylindrical objects. A typical product finished by grinding is a ball or roller bearing.

How to identify pieces finished by precision grinding: a very smooth, high precision flat or round surface with no machining marks, often (but not always) fairly shiny.

An ordinary grinding wheel guided by hand is often used to clean parting lines and other defects off castings. Unlike precision grinding, this does not leave accurate flat or even surfaces, although it can produce a very smooth surface.

(b) Cutting Screw Threads

External or internal screw threads can be cut in the lathe in an operation similar to turning in which the motion of the tool bit is directly linked to the rotation of the



(French & Vierck, *Engineering Drawing*, McGraw-Hill 1947.)

workpiece. However, this is a slow operation and not suited to mass production. External threads are usually cut by a special cutting tool called a **threading die** (or simply a die), which is pushed over the rotating workpiece. Internal threads are usually cut by a **tap**, which is a cutting tool like a screw that is rotated into a hole of suitable size. Threads may also be formed by rolling: hardened steel rollers are pushed into the rotating workpiece. Large quantities of screws and other small parts are produced by a special type of automated lathe called a **screw machine**.

(c) Boring Mills

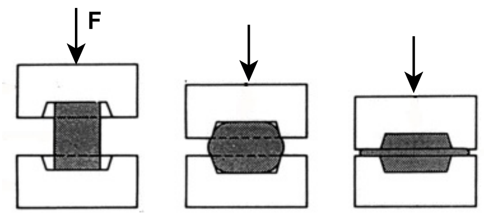
Boring mills are specialized machine tools for large pieces of work. A vertical boring mill is essentially a large lathe with a vertical axis, with the workpiece rotating around this axis. A horizontal boring mill is similar to a large milling machine, with cutters rotating about horizontal axes to finish the work. Unlike the milling machine, however, it is the cutters, not the work, which are moved along axes to reach different parts of the work.

(d) CNC (Computer Numerically Controlled) Machine Tools

Many machine tools are automated and controlled by computers, which are usually capable of taking a CAD drawing and converting it to machining instructions. The most common CNC machines are automated milling machines, often referred to as machining centres. These are classified according to the number of axes about which the workpiece can be moved: 3 axis refers to x, y, and x motions only, while 4 and 5 axis machines add the capability of rotating the workpiece about one or more axes during machining operations.

4. Forging

Forging refers to the production of a finished part by forming a blank under pressure between two dies (steel moulds). It is usually performed hot - that it, with metal which has been heated to a temperature at which it becomes plastic (about 1100 °C for steel) - but it is sometimes done cold.



Process description: The blank - a piece of bar of roughly the same size as the finished piece - is placed on the lower die, and the upper die is then forced down on it by a press, causing the material to flow plastically. Any excess of metal is forced out of the mould, forming a parting line like that of a casting (sketch). Undercuts and internal cavities cannot be produced, surfaces are somewhat rough. Like castings, pieces must be machined afterwards if precise surfaces are required.

Advantage of forging: the flow of metal (extensive plastic deformation) tends to produce a very strong part. Often used to produce tools, crankshafts and other components where strength is important.

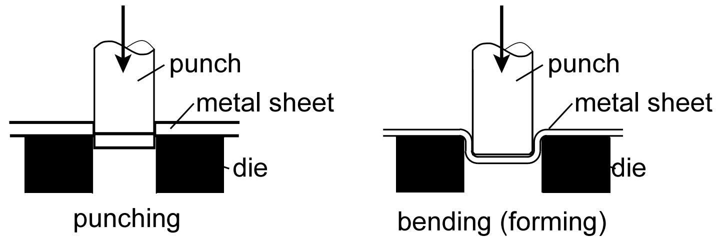
How to identify pieces that have been made by forging:
- usually steel, fairly simple shapes, fairly smooth surfaces, no internal cavities, straight parting line between die halves

It is often difficult to distinguish forged pieces from sand cast pieces.

Reference: *Marks' Standard Handbook* p. 13-23 - 13-26

5. Sheet Metal Forming

Stamping



This process uses punches and dies in a press to produce parts from sheet metal. If the punch is a close fit in the hole in the die, it will cut a hole in the sheet; if there is some clearance between the punch and the hole, it will bend the metal instead (see sketches). This principle can be used to produce a large variety of holes, bends, raised areas and other shapes. Very large and complex pieces, such as automobile body panels, can be produced with large presses and suitably shaped dies.

How to identify parts made by stamping:
- part is thin sheet metal of approximately uniform thickness (thickness may vary a bit owing to stretching of metal, but is essentially the same as the thickness of the original sheet)

Note that the very thin metal sections of a sheet metal part *cannot* be produced by machining.

Stamping can be used to punch pieces out of metal several mm thick. Such pieces often show parallel marks like machining marks on the sides, left by the motion of the punch, but the surface finish is not as good as that produced by machining, and the punch often leaves rounded corners on the top of the piece.

Deep Drawing

Metal containers and deep indentations may be made by using a punch to force the material into a die, similar to the bending operation shown above but with much greater depths. The material undergoes a great deal of plastic deformation during this process; hence the metal must be very ductile, or it will fail. A typical deep drawing product is a beer can.

Reference: *Marks' Standard Handbook* p. 13-16 - 13-22