Sheet metal operations - Cutting and related processes

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1.Cutting and related processes:

1.1 Introduction:

Sheet metal forming, also called stamping, involves operations such as cutting, drawing, spinning etc on sheets. Sheet metal forming involves predominantly tensile forces, compared to bulk forming, which involve compressive forces. Due to tensile stress, sheets may undergo localized deformation followed by cracking. Sheets are rolled products, which have thickness less than 6mm. Sheet metal operations involve work pieces with large surface area to thickness ratio. Blanks are cut from sheets. These blanks are subsequently subjected to one or more sheet forming operations in order to get the finished component. Sheet metal forming is widely used for producing wide range of products starting from household vessels to aerospace parts, to automobile or aircraft bodies. Final shape is obtained by applying tensile, shear or combination of forces and stretching or shrinking the sheet metal blanks.
Hydraulic or mechanical presses called stamping presses are used for the forming process. Die – punch combination is used for the process to impart the desired shape to the blank. Dies may be simple or compound, which include several operations. Transfer dies can be used in heavy operations.

The prominent type of force in sheet forming is tensile. In some operations shear is also used. However, reduction in sheet thickness is avoided in sheet forming, due to localized deformation called necking. Yielding, elongation, anisotropy, and wrinkling are important parameters in sheet forming. Material grain size also influences the characteristics of the formed product.

During tensile elongation of ductile material, beyond the ultimate tensile strength, localized necking begins. At the ultimate point where necking or instability is about to begin, we know that the strain is equal to the strain hardening exponent. Higher the strain hardening exponent for a metal, higher the stress it can withstand before necking. In isotropic materials, necking is usually found to occur at an angle of 55 degrees with reference to the tensile axis.
Larger strain rate sensitivity parameter leads to diffuse necking (uniform) rather than localized. This means larger amounts of uniform elongation occurs before fracture of the sheet metal.

The phenomenon of yield point in some materials such as low carbon steels produces Lueder bands. Such bands also called stretcher strains produce undesirable elongated marks on the sheet metal. Temper rolling or skin rolling could be used for eliminating these marks. Anisotropy – both normal and plastic anisotropy due to processing of sheet metals has notable influence on the forming. Coarse grain structure results in rough surface on the formed sheets. This is called orange peel effect. Residual stresses due to non-uniform deformation, wrinkling due to compressive stress are also important issues in sheet metal forming. In the following sections we discuss the various sheet metal operations.

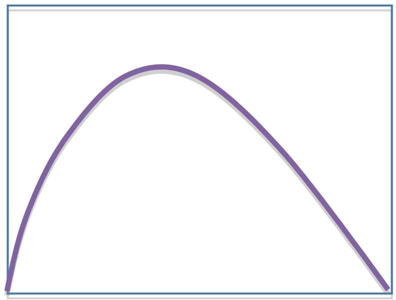
1.2 Shearing, blanking, punching:

1.2.1 Shearing:

Shearing is the process of cutting off of sheets using a die and punch, applying shear stress along the thickness of the sheet. A die and punch or a pair of blades are used in shearing. Shearing happens by severe plastic deformation locally followed by fracture which propagates deeper into the thickness of the blank. The clearance between the die and punch is an important parameter whichdecides the shape of the sheared edge. Large clearance leads to rounded edge. The edge has distortion and has burr. The shearing load is also higher for larger clearance. For harder materials and larger sheet thickness, larger clearances are required. Generally, clearance can vary between 2% and 8% of the sheet thickness. Usually shearing begins with formation of cracks on both sides of the blank, which propagates with application of shear force. A shiny, burnished surface forms at the sheared edge due to rubbing of the blank along the shear edge with the punch or the die wall. Shear zone width depends on the speed of punch motion. Larger speed leads to narrow shear zone, with smooth shear surface and vice-versa. A rough burr surface forms if clearance is larger. Similarly, a ductile material will have burr of larger height.
Shearing a blank involves plastic deformation due to shear stress. Therefore, the force required for shearing is theoretically equal to the shear strength of blank material. Due to friction between blank and tool, the actual force required is always greater than the shear strength. Variation of punch force during shearing process is shown below. The maximum force required on the punch for shearing can be empirically given as:

$F_{max} = 0.7\sigma_u tL$

t is blank thickness and L is the length of the sheared edge. For reducing the shearing force, the cutting edges of the punch are made at an angle. This ensures cutting of a small portion of the total length of cutting.



1.2.2 Shearing zone geometry:

Considering the shearing of a blank, we understand that the top surface of the sheet where the punch contacts the blank, a small projection called rollover forms. This region corresponds to the small depression made by the punch on the sheet. Below this, the burnished surface which is a smooth surface formed by the rubbing of the shear surface against die and punch is present. The burnished surface is located below the rollover in case of a blank. Whereas, the burnished region is located on the upper side in case of a punched sheet. In the case of a punched hole on a sheet, the fracture zone is located below the burnished zone. The burr forms below the fracture zone. Burr is a sharp edge formed at the end of the process due to elongation of the material before completely getting severed off. The depth of the deformation zone depends on the ductility of the sheet metal. If ductility is small, the depth of this zone is small. The depth of penetration of the punch into the sheet is the sum of the rollover height and burnishing zone height. The depth of rough zone increases with increase in ductility, sheet thickness or clearance. There is severe shear deformation in the fracture zone.

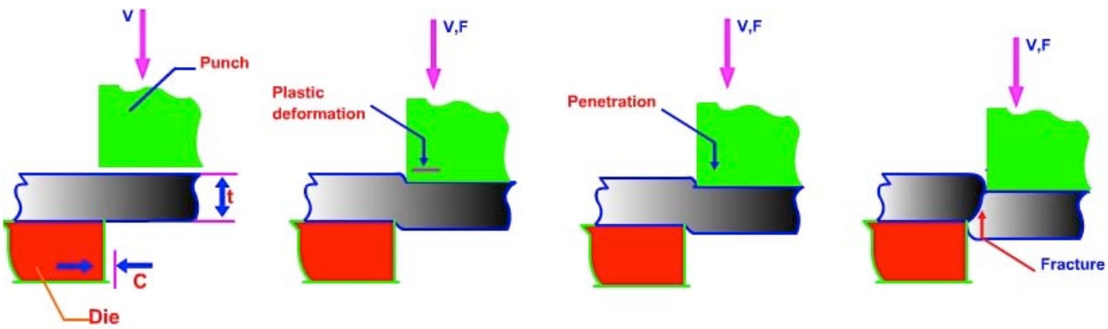


Fig. 1.2.1: Stages of shearing operation

1.3 Blanking and punching:

It is a kind of shearing operation, carried out along a closed contour. The desirable part in this operation is the metal inside the sheared contour, called blank. Example is making circular blanks out of sheets for subsequent deep drawing of cups.

Punching is the operation in which the desired part is the sheet left out after making a punch hole or contour shearing.
Die-punch clearance is very critical for blanking and punching, as it governs the kind of finish obtained on the final part. Typical recommended clearances for the operations are given in table below:

Table 1.3.1: Radial clearances for blanking and punching:

Material	Radial clearance as percentage of thickness		
	High precision	Good finish	General
Aluminium	1	4-6	10-12
Low carbon steel	1-2	5-7	9-11
Stainless steel	1-2	4-5	10-12
Brass	1	2-5	7-10

Punch diameter has to be smaller than the die hole. The clearance between die and punch is based on the type of process.
For blanking operation for obtaining a blank of diameter Db the clearance is given on the punch.Diameters of punch and die are given by:

Dia of punch = Db-2c and die diameter = Db, where c is radial clearance.

For punching operation on a sheet with a hole of diameter Dh,
the die hole diameter = Dh+2c
the punch diameter = Dh

In general, the clearance can be expressed as:
c = At, where A is clearance allowance and t is sheet thickness.
The clearance allowance A is taken to be 0.075 for most of the steels and 0.045 for aluminium alloys.

For easy removal of slug during punching or blanking, a small angular clearance of 1 degree to 1.5 degree is provided in the die hole.

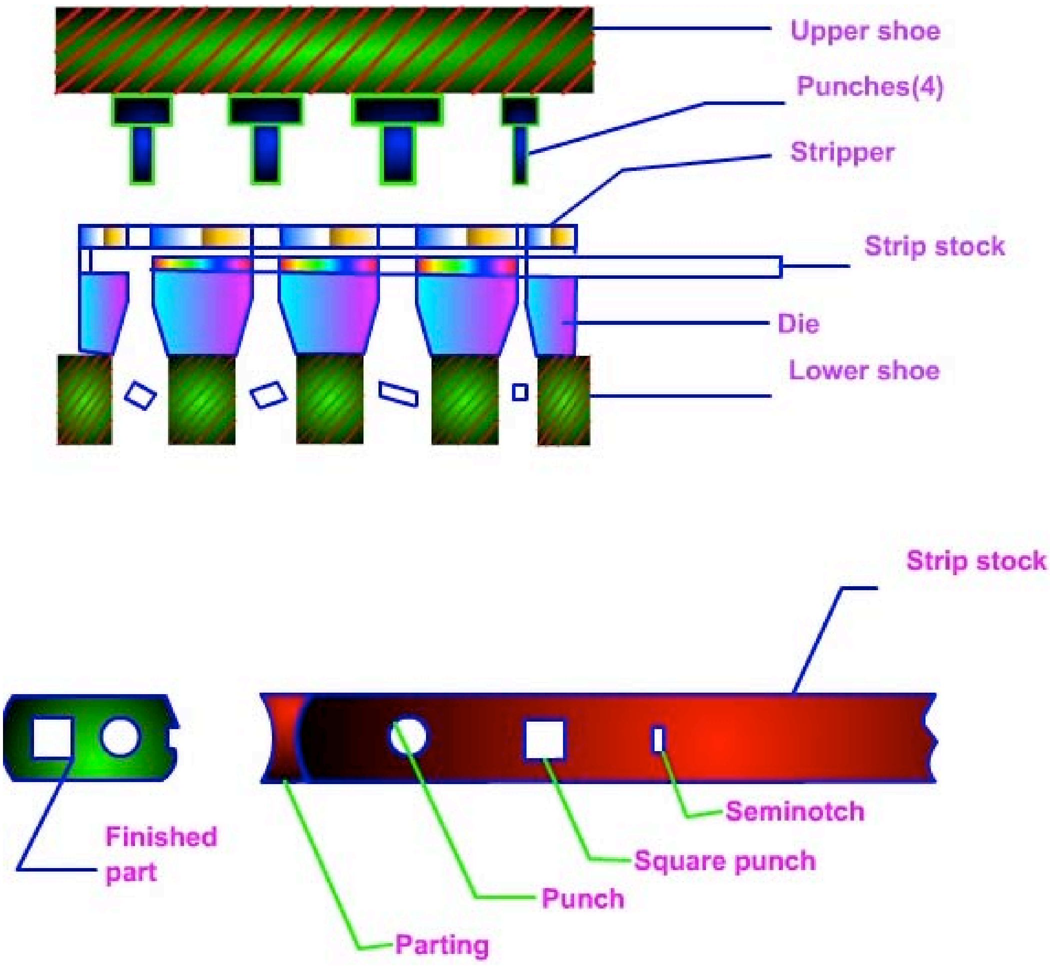


Fig. 1.3.1: Blanking and punching

1.4 Cutting:

Shearing off of the entire sheet for producing a number of pieces of various contours is done by cutting. Perforating, slitting, parting are also cutting operations. Slitting is carried out with a pair of circular blades. The rotary cutters slit the sheet along straight line or along a closed contour. The blades or either rotated by power or kept idling through which the sheet is pulled.

Trimming is a finishing operation in which a previously formed part is finished in its contour by shearing off of the burr and excess material.

Shaving is a finishing operation in which shearing off of burrs from the cut edges is carried out in order to make the edges smooth and also impart dimensional accuracy.

Cut off operation involves removal a blank from a sheet metal by cutting on opposites sides, sequentially. The cut edges need not be straight.

Punching of holes of different contours is called perforating. Slotting is making elongated holes such as rectangular holes in sheet metal.

Cutting off a small part from the edge of a sheet is called notching.

1.4 Fine blanking:

It is a finishing operation in which shearing is done with small clearances – about 1% - and close tolerances in order to achieve dimensional accuracy. It is a single step finishing operation. Square and smooth edges are produced applying clamping force on the blank. This prevents distortion of the sheet during operation. A hold down ring or pressure pad with a v-shaped projection is used for holding the top side of the sheet tight during the application of the shear force. At the bottom of the sheet a pressure pad is also used. A triple action press with individual control of the die, punch and pressure pad is used for the operation. Usual sheet thickness ranges between 0.5 to 12 mm.

Material loss in cutting off operations involving sheet metals may be as high as 30%. Arranging the shapes to be cut on the sheet properly so that waste is reduced is called nesting. CAD is used nowadays for this purpose.

1.5 Shearing and forming tools:

A punch with flat tip is seldom used for shearing because the required load is higher. This is due to the fact that the entire thickness of the sheet is sheared simultaneously. The area over which shearing happens at a given instance can be reduced by making the punch end beveled. For thick sheets, beveled punches are preferred because there is considerable reduction in shear load. Single or double bevels are common in case of circular punches. In such cases, lateral rigidity is to be ensured. Die and punch are made of tool steel or carbide.
Forming using hand operated presses is limited to finishing operations. Mechanically or hydraulically operated presses are used for high volume sheet forming. Mechanical presses are quick-operating whereas hydraulic presses are slow-operating but have long strokes.
Clamping pressure or hold down may be required in some sheet forming operations in order to hold the sheet during forming. This will prevent wrinkling of the sheet. In double acting presses, one stroke may be utilized for hold down.
Compound dies are those which have several dies in a single setup. Such dies can be used for making several operations in a single stroke for improved productivity.
Progressive forming refers to the successive forming of the different stages of forming a part using the same tool set with a number of strokes. Making of washers is an example of progressive forming. First a hole is punched during first stroke. Then the sheet is moved to the next position when the blanking operation is carried out. Simultaneous punching and blanking operations can be made in the same stroke using different punches.

Transfer dies are applicable where different operations are to be carried out on the same sheet successively on a series of stations, along a straight path or a circular path.

Example 1:
The shear strength of a cold rolled steel is 300 MPa. Determine the punch force required for making a blank of 120 mm diameter from a strip of 3 mm thickness ofthe above material. What is the maximum punch force required?

Theoretical punch force requires can be calculated from the shear strength.

F = Shear strength X perimeter of the blank X thickness of blank = $300\pi 120X3$ = 339.4 kN

Maximum punch force can be calculated using the equation:

$F_{max} = 0.7\sigma_u tL$

Assuming σ_u = 2 Shear strength = 2X300 = 600 MPa

Fmax = 474.8 kN

Example 2:
A cold rolled steel sheet with a shear strength of 350 MPa and a thickness of 3 mm is to be subjected to blanking operation. The diameter of the blank to be obtained is 130 mm. What is the appropriate die and punch diameter and punch force required for the operation?

The clearance for blanking operation can be taken to be 0.075.

Punch and die diameters for blanking operations are given by:
Dia of punch = Db-2c = 130 – 2X0.075 = 129.85 mm
Dia of die = Blank diameter = Db = 130 mm

Punch force = τLt = 350πDt = 428.61 kN