An Overview Of Sheet Metal Forming

In Sheet Metal Forming, a plane sheet is formed to the desired more complex shape. Numerous parts are made by sheet metal forming including car body and inside panels, airplane outer body, brackets, pans, deep drawn components, hardware stampings and bent angle and channels. Very small components to large components are made by Sheet Metal Forming.

Sheet forming includes many processes that form the sheet including brake bending, stamping, deep drawing, stretch forming, hydroforming and roll forming. Most of the forming is done at room temperature. Hot sheet forming is also done for some high strength materials.

The advantages of sheet metal forming are (a) small to large lots can be manufactured, (b) Very tight tolerances can be held if needed and (c) micro to very large sizes can be manufactured.

Strain is a measure of deformation. It is defined as a change in length divided by length. Strain is called 'True' Strain' if change in length is divided by the length at the time strain is defined. It is called 'Engineering Strain' if the change in length is divided by the original length.

If the sheet metal surface has strain in two directions, a circle drawn on the surface would distort depending upon whether the strains are tensile or compressive. Knowing the dimension of circle before deformation and dimension of distorted circle after deformation, the strain in two directions can be calculated.

The deformation of sheet can be elastic and/or plastic. Elastic deformation is recovered when load is removed but plastic deformation is a permanent change. Sheet always deforms elastically first and then deforms plastically only when the stress exceeds a certain limit. In bending, the angle of bend increases after load is removed due to recovery of elastic deformation.

In elastic deformation, Hook's law applies. The ratio of stress over strain is a material constant called Modulus of Elasticity. In plastic deformation, the volume of the material does not change. This principle allows calculation of dimensions of formed part at different forming stages. Another principle of plastic strain is that the effective strain due to any type of deformation is always positive and adds to the existing strain in a part. If a part is bent, the bending strain is added to the part strain. If the bent part is unbent in another operation, the unbending also adds to the strain even though part shape is brought back to the original shape before bending. When formed cold, most metals become stronger as they are plastically deformed. This phenomenon is called Work Hardening. When compressive stress in sheet metal exceeds a certain limit, the metal buckles causing ‘Wrinkling’. The stress limit depends upon the thickness of the sheet.

Sheet metal parts of many materials are cold formed. Some are also hot formed. These materials include low carbon steels, stainless steels, aluminum alloys, copper alloys, brass, titanium alloys, Monel and special steels. Whether a sheet metal can be formed to a certain shape depends upon its two basic characteristics. These are resistance to deformation and extent to which it can be deformed without necking or fracture. Material properties relevant to forming are yield strength, tensile strength, strain hardening exponent, strain rate sensitivity and strain ratio. These properties can be determined through standard tensile tests.

In tensile tests, a standard test specimen is stretched till it breaks. During the test, elongation of gauge length and load are measured. From the data, properties such as yield strength, UTS, uniform elongation and total elongation before fracture are determined.

As the stress increases, at some point, the deformation changes from elastic to plastic. The stress at this point is the Yield Strength of the material. As the stress is further increased, the material starts to neck at a stress called Ultimate Tensile Strength. The specimen elongation up to UTS point is uniform. This elongation is called Uniform elongation. If the stretching is continued, most of the deformation occurs at the neck. Eventually the specimen breaks at the neck. From the load-displacement data, engineering stress-strain and true stress-strain plots can be created. The stress-strain can be fitted to a power equation which gives the strain hardening exponent (n). The stress-strain of a material represents its resistance to deformation. The strain hardening exponent (n) is one of the parameters that define the formability of a sheet material.

Since the sheet is made by rolling process, there is directional variation of mechanical properties in a sheet. ‘Planar Anisotropy’ represents anisotropy in plane of the sheet and ‘Normal Anisotropy (R)’ represents it in thickness. Formability is known to be dependent on R. R is defined as ratio of width strain divided by thickness strain. ‘Ears’ formed in a deep drawn cup are due to planar anisotropy.

Low carbon steels used in sheet forming are identified by chemistry, quality level or designation as Commercial quality, Deep Drawing quality, Interstitial free and Vacuum degassed. Special steels include HSLA different grades, Dual-phase, Vacuum-Degas, Interstitial-Free and Bake-Hardenable. Stress strain plots, values of strain hardening exponent (n) and normal anisotropy for most materials are available. For sheet metals, formability is the ability to be formed to desired shape without necking or cracks. Stretch forming tests such as Olsen and Ericson dome test and Limiting Dome Height (LDH) test are used to define the formability of sheet metals.

In Deep Drawing process, a sheet metal blank is radially drawn into a die by a moving punch. The parts are usually long with length more than 1-2 times the width. Many parts, simple and complex such as cups, nozzles, caps, pans and other tubular parts are made by Deep Drawing process. During the drawing of material by the punch, the wall of the material around the punch supports the punch load. If the punch load becomes excessive, the wall necks or breaks. For every material, there is a maximum ratio of blank diameter to cup diameter beyond which the cup drawing fails. This ratio is called limiting draw ratio (LDR). To draw deeper parts, the deep drawing is done in multiple operations.
Drawn cup is redrawn in a straight drawing or in a reverse drawing.
The number of operations required to form a deep drawn part depends upon the material, sheet thickness and shape of the part.

The LDR for a material of certain thickness is usually different for the first drawing operation and subsequent redrawing operations. For a low carbon steel of thickness of .015 in, LDR may be 2.0 for first step and 1.33, 1.28, 1.25 for subsequent steps.
Because of anisotropy, the height of the drawn cup will not be uniform. A trimming operation is usually required near the last operation. For circular part, the diameter of the initial blank can be easily calculated using volume constancy principle. For complex parts, the shape of starting blank is developed from experience, trial-and-error or using a software.

Machine for Deep Drawing is usually a mechanical press or a hydraulic press or a variation of these types. The machine can be single action, double action or triple action depending upon the part being formed. A single-action press has only one ram and an ejector. The draw punch is fixed to the ram and the blank holder is operated from the die cushion.
The double-action press has two rams and an ejector. The draw punch is mounted on the inner ram and the blank holder on the second ram for deep drawing. In a mechanical press, the available load decreases away from the bottom dead center. In hydraulic press, the available load is constant throughout the stroke. Also, maximum load can be changed by adjusting the fluid pressure in a hydraulic press. Newer mechanical presses offer servo drive that allow programmable change in speed. This feature allows speed, stroke, and tonnage optimization. Newer hydraulic presses also offer programmable change in ram speed, dynamically controlled die cushions and ram and bed ejector options.

Bending is a forming process to bend the sheet material along an axis. It is used in manufacture of a variety of parts that have ‘V’, ‘U’ and other channel shapes. In bending, the neutral axis which lies at the mid thickness bends beyond the elastic limit. On removal of load, there is a permanent change in shape. In air bending, the punch and workpiece do not bottom on die. On removal of load, the elastic strain recovery causes a change in bend angle. The neutral axis moves from center of the thickness when sheet is bent. Bend allowance is the length of the neutral axis between the bend lines. It is calculated using a factor that depends upon the material and its thickness.

Flanging is like bending. Flanging is a forming process in which a narrow strip at the edge of a sheet is bent down along a straight or curved edge. Three major types of flanges in sheet metal are straight, shrink and stretch flanges. In stretch flanging, edge splitting can be a problem in some cases. Notches are put on flanges to eliminate splitting.

Stretch forming is a method that combines controlled stretching and bending of sheet metal blanks. During stretching, the metal is stressed in tension to slightly above its yield point to cause plastic deformation. Sufficient stretching and bending results in a part that retains its shape after release of load. Stretch forming is extensively used in the aerospace industry. Using large machines, wing members, tail structures and engine components are made using this process.

Stamping is a general term covering press operations which include stretching, drawing and other operations done on sheet metal. The forming dies in stamping include operations of bending, flanging, stretching, embossing, beading, drawing, ironing, bulging and coining. Multiple operations required to manufacture a sheet metal part may be done either on multiple machines or at multiple stations in a single stroke. Many different die designs such as compound dies, progressive dies and transfer dies are used depending upon part shape and lot size.

Forming of complex parts includes bending, drawing, and stretching of sheet metal. To resolve issues of excessive thinning or cracks, one experimental technique commonly used is strain measurement on the surface and comparing to Forming Limit Diagram of the material. Forming Limit Diagram (FLD) of a material shows the limit of forming. It plots the major strain at onset of necking for all values of minor strain. FLD can be determined experimentally by stretching strips of varying width over a spherical dome. The strips have circular grid marked photographically. Varying width gives different ratios of major strain over minor strain. The strips are stretched till a perceptible neck is observed.

For diagnosing problem in any application, circular grid is printed on the starting sheet blank. At any stage of interest, the major and minor strains in the formed sheet at critical locations are measured from the distorted grid and plotted on FLD. This comparison points to the locations that need design/tooling modification. This type of analysis helps in making changes to tools to avoid necking of material at critical locations.

Several process design and FEA simulation software are available to assist in design and manufacturing of parts by sheet metal forming. Software is available to unfold a stamped part to get the starting blank shape and dimensions. These are based on special techniques or reverse FEA simulation and can reduce trial-and-error experimentation.

For progressive die design and tooling design, software are available that deskill the design process and significantly reduces the time taken to design the tooling. FEA simulation software helps in validating the design and in resolving issues related to spring back, splitting, necking and fracture. From expensive software that covers all phases of manufacturing a sheet metal formed part to small inexpensive software that assists in a single phase of design are available.

This overview briefly provides basic knowledge on Sheet Metal Forming. It briefly covers basic metal deformation in sheet forming, materials properties and formability, various sheet forming processes, use of Forming Limit Diagram for diagnosis of problems in forming and available design and simulation software.