Formability

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1. Formability

1.1 Introduction:
Formability is a term applicable to sheet metal forming. Sheet metal operations such as deep drawing, cup drawing, bending etc involve extensive tensile deformation. Therefore, the problems of localized deformation called necking and fracture due to thinning down are common in many sheet forming operations. Anisotropy also is a major concern in sheet metal operations. Formability is the ease with which a sheet metal could be formed into the required shape without undergoing localized necking or thinning or fracture. When a sheet metal is subjected to plane strain deformation, the critical strain, namely, the strain at which localized necking or plastic instability occurs can be proved to be equal to $2n$, where $n$ is the strain hardening exponent. For uniaxial tensile loading of a circular rod, the critical or necking strain is given to be equal to $n$. Therefore, if the values of $n$ are larger, the necking strain is larger, indicating that necking is delayed. In some materials diffuse necking could also happen. Simple uniaxial tensile test is of limited use when we deal with formability of sheet metals. This is due to the biaxial or triaxial nature of stress acting on the sheet metal during forming operations. Therefore, specific formability tests have been developed, appropriate for sheet metals. Loading paths could also change during sheet metal forming. This may be due to tool geometry or metallographic texture.

1.2 Forming limit diagram (FLD):
Forming limit diagram is a very effective way of optimizing sheet metal forming. A grid of circles is etched on the surface of a sheet metal. Then the sheet metal is subjected to deformation. Usually the sheet is deformed by stretching it over a dome shaped die. Strips of different widths can be taken for the test, in order to induce uniaxial or biaxial stress state. The circles deform into elliptic shapes. The strain along two principal directions could be expressed as the percentage change in length of the major and minor axes. The strains as measured near necks or fracture are the strains for failure. A plot of the major strain versus minor strain is then made. This plot is called Keeler-Goodwin forming limit diagram. This plot gives the limiting strains corresponding to safe deformations. The FLD is generally a plot of the combinations of major and minor strains which lead to fracture. Combination of strains represented above the limiting curves in the Keeler-Goodwin diagram represent failure, while those below the curves represent safe deformations.

A typical Keeler-Goodwin diagram is shown below. The safe zone in which no failure is expected is shown as shaded region. Outside this zone there are different modes of failure represented at different combinations of strains. The upper part of the safe zone represents necking and fracture.
Strains above the curves result in failure.

Fig. 1.2.1: Keeler-Goodwin diagram

The slope of the right hand side curve (necking curve) is found to decrease with increasing values of the strain hardening exponent, \( n \). Similarly, variations in sheet thickness, composition,
grain size all reduce the slope of the neck curve. The safe region is narrowed down by biaxial stress state. Sheet thickness also has effect on FLD. Higher sheet thickness increases the FLD.

3.3 Formability tests:
In cup drawing process, a formability parameter known as limiting draw ratio is very useful. LDR is defined as the ratio of the initial diameter to the diameter of the drawn cup. Many tests have been evolved for determination of limiting draw ratio of sheet metals. Cupping tests such as flat bottom test, hemispherical cup test and conical cup test are used for determining LDR. In swift cup draw test cups with flat bottom are drawn from circular blanks. Each time the diameter of the sheet is increased. The maximum diameter of the sheet which can be successfully drawn is determined, from which LDR can be found.

![Fig.1.3.1: Schematic of Typical formability test for sheet metal](image)

In Olsen and Erichsen test, the sheet is stretched over a hemispherical tool to form a dome cup shape. The height of the dome is considered as index of drawability. In Fukui test the sheet is both drawn and stretched over a cup of conical shape. Both drawing and stretching happen. The circular blank is drawn through a conical die with a circular punch without using a blank holder. The ratio of minimum diameter at which crack does not appear to the initial diameter of the blank is taken as a measure of formability of the sheet metal.
In another test known as OSU formability test, cylindrical punches of three different tip geometries are used to penetrate the sheet which is held clamped on both ends. One has to measure the height of the drawn part of the sheet at the instance of failure.

If larger strains are to be introduced hydraulic bulge test is the most appropriate. In this test, the sheet metal is subjected to oil pressure, after being placed on a circular hole and clamped. The oil pressure, radius of curvature of the sheet and radial strain are to be known in order to plot the stress-strain curve.

![Fig. 1.3.2: Fukui Cup Drawing Test](image1)

The stress strain plots can be obtained after the test in order to understand the extent of strain undergone by the sheet before fracture. It is found that the strain rate sensitivity parameter $m$ has effect on the uniform elongation after necking. Higher values of $m$ promote larger uniform elongation after necking. It is also found that the cup height increases with higher strain hardening exponent. This is due to the delayed necking with higher strain hardening exponent values.

![Fig. 1.3.3: Swift cup test](image2)
1.4 Anisotropy on formability:
In deep drawing of sheet metals, anisotropy of the material is known to be beneficial. Anisotropy is the variation in properties with respect to directions, due to variations in microstructures introduced in forming operations such as rolling. In rolling, the grains are elongated along the rolling direction. As a result, tensile properties differ along different directions. The rolled sheet can be subjected to uniaxial tensile test. The true strains along the thickness and width directions can be determined. If \( w \) is the width of the sheet and \( t \) is thickness of the sheet, the normal anisotropy \( R \) is defined as:

\[
R = \frac{\ln \frac{w_f}{w_i}}{\ln \frac{t_f}{t_i}} = \text{true width strain} / \text{true thickness strain of the sheet.}
\]

If \( R = 1 \) then both height and width strains are equal – this corresponds to isotropic material. \( R \) also depends on orientation of the material with respect to the rolling direction. \( R \) can be estimated along the direction of rolling, angle of 0°, at an angle of 45° with respect to rolling direction and perpendicular to rolling direction. We can define the normal anisotropy as:

\[
\bar{R} = \frac{R_0 + R_{90} + 2R_{45}}{4}
\]

Note: A value of \( R = \infty \) results if the thickness strain is equal to zero. This means there will be no thinning effect on a sheet subjected to tensile deformation. Therefore, in sheet forming, especially in deep drawing, we prefer high value of \( R \) (3 to 5) in order to ensure little thinning.

Similarly, the planar anisotropy is defined as:

\[
\Delta R = \frac{R_0 + R_{90} - 2R_{45}}{2}
\]

The normal anisotropy represents the average of anisotropy variation in all directions. The planar anisotropy gives the variation of anisotropy with direction.
Figure above depicts the variation of anisotropy with respect to the direction of rolling. In deep drawing a sheet with higher anisotropy is preferred because the stress conditions in flange and the cup wall sections will be different. Cups with deeper walls could be drawn from materials with greater anisotropy. Further, with increase in normal anisotropy, the flow stress of the material decreases. Increased flow stress in the cup section of the deep drawn part, the strength of the cup section is increased. Therefore, formability of sheet metal in deep drawing can be said to be improved with increase in $\bar{R}$. However, an increase in planar anisotropy, $\Delta R$ is known to have a negative effect in deep drawing. Higher values of this anisotropy will introduce earing, a variation of the cup height around its wall circumference. In stretch forming the anisotropy parameter seems to be less significant. In deep drawing, the strain hardening exponent, n seems to be less significant.