Using limiting draw ratio to evaluate material drawability, Part I

Concepts and testing parameters

BY ALI FALLAHIAREZOODAR, TINGTING MAO, AND TAYLAN ALTAN

Editor's Note: This article is Part I of a two-part series describing the use of limiting draw ratio (LDR) to determine the drawability of materials. Part I describes the concept of LDR and the parameters that affect LDR tests. Part II, to appear in the July/August issue, will discuss finite element simulation for predicting the LDR.

Information about the drawability of a sheet material and thickness is essential for stampers to prevent part failure and to ensure they are using appropriate tool designs and forming conditions. However, there is no direct way to determine material drawability, especially for recently developed high-strength alloys. For instance, the standard tensile test is insufficient to estimate drawability because it presents a uniaxial strain state, but most complex forming processes involve a complex strain state.

One of the most commonly used procedures to determine drawability is the limiting draw ratio (LDR) test. LDR is the ratio of the maximum blank diameter to the punch diameter that can be drawn successfully without failure (see **Figure 1**). LDR can be determined by experimental tests, analytical method, and finite element (FE) simulation.

During an LDR test, successful drawing implies that there is no necking or wrinkling in the drawn cup, which has no flange at the end of the process. Several die and process parameters affect the LDR and depend on the sheet material properties and the testing conditions.

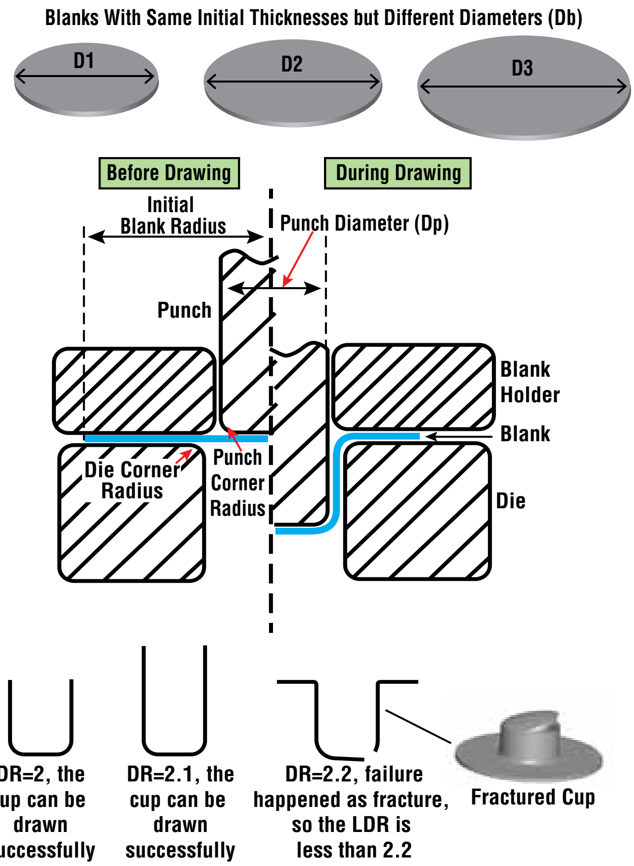

Figure 1

In the cup drawing test, the ratio of the maximum blank diameter that can be drawn successfully without failure to the punch diameter (max Db/Dp) determines the LDR.

Material and Tool Parameters Affecting the LDR

The most important material property affecting LDR is normal anisotropy, or *r-value*. Based on the microstructure and material flow, sheet materials can be categorized as isotropic (r-value = 1) or anisotropic (r-value ≠1).Normal anisotropy (r) measures the change in material characteristic with respect to thickness. Materials with higher r-value usually show better drawability and higher LDR. Steels with extra-deep drawing quality (EDDQ) are well-known for high r-values from 1.5 to 2.2.

The strain hardening exponent, or *n-value*, is the other material property that affects LDR. The n-value is the strain hardening exponent in a true stress (σ) versus true strain (ε) curve ($\sigma = K\varepsilon^n$), which commonly is used to describe the flow stress data in the plastic region. The n-value is an indication of strain hardening and affects material formability. In general, the larger the n-value, the more formable the sheet material.

Friction, as expressed by the value

of the coefficient of friction (CoF), also affects the potential failure of the drawn cup. CoF depends on the selected lubricant, surface conditions and coatings of the sheet and die, and the blank holder pressure on the flange. During LDR tests, the CoF should be reduced as much as possible because large CoF results in large punch forces and stresses in the cup wall, increasing the probability of fracture in the drawn cup.

The punch/die geometry affects LDR tests significantly. The radius of the die corner plays an essential role in metal flow and stress distribution during the drawing process. Decreasing the die corner radius increases the stresses and strains resulting from the bending and unbending of the sheet during drawing into the die. Therefore, a smaller die radius leads to a smaller LDR. The punch corner radius also affects the LDR. In LDR tests, most failures happen in the area near the punch corner radius (see Figure 1). A smaller punch corner radius leads to sharp bending of blank material, increasing the possibility of failure and decreasing the LDR.

Testing Conditions Affecting LDR

Forming speed and sheet and tool temperature affect the cup drawing process. Higher temperature allows for deeper drawing and more stretching by decreasing the flow stress and increasing the ductility of the sheet metal while reducing the viscosity and the effectiveness of the lubricant. However, most LDR tests are conducted at relatively low punch or forming speeds and at room temperature. Thus, temperature effects often can be ignored.

In cup drawing, the blank holder controls the flow of material into the die and reduces the formation of wrinkles in the flange. However, because of the friction between the blank holder and the sheet in the flange area, the blank holder force affects friction and metal flow. Therefore, an optimum blank holder force must be determined for each drawing operation based on the sheet material, thickness, and testing conditions to keep the friction shear stress in the flange area as low as possible while preventing wrinkle formation.

Material	AA5754-O	SS304
Initial Blank Thickness (mm)	1.3	0.87
Punch Diameter (mm)	40	40
Die Diameter (mm)	44.6	44.6
Blank Diameters (mm) (Drawing Ratio)	100,104,112,120 (2.5), (2.6), (2.8), (3)	84, 92, 96, 100 (2.1), (2.3), (2.4), (2.5)
Blank Holder Force (kN)	10	10
Die and Blank Holder Temperatures (°C)	250, 275, 300	25, 70, 100, 150

Figure 2

These are the tool geometry and testing conditions for the LDR test of AA5754-O and SS304. The elevated-temperature test used a heated blank holder and cooled punch.

Experimental Results

Several studies have been performed to determine the LDR using analytical or FE simulation methods. One study, conducted to determine the LDR for two conventional automotive aluminum alloys (AA6111-T4 and AA5754-O), showed that increasing the die corner radius increases the LDR for both alloys. Increasing the die corner radius from 3 mm to 12 mm increased the LDR for AA5754-O and AA6111-T4 from 1.44 to 2.16 and 2.03, respectively. This study also showed that AA5754-O had a better drawability and larger LDR than AA6111-T4.

In another CPF experimental study, the effect of temperature on drawability of AA5754-O and SS304 was investigated. Tool geometry and testing conditions are summarized in **Figure 2**, and results are summarized in **Figure 3**. The results show that increasing the temperature increases LDR for both.

Material	Die and Blank Holder Temperature (°C)	LDR
AA5754-O	250	2.6
	275	2.8
	300	2.8
SS304	25	2.1
	70	2.3
	100	2.3
	150	2.5

Figure 3

Temperature has an effect on LDR with a heated blank holder and cooled punch.

Ali Fallahiarezoodar and Tingting Mao are graduate research associates at the Center for Precision Forming (CPF) at The Ohio State University, 339 Baker Systems, 1971 Neil Ave., Columbus, OH 43210, 614-292-5063, fallahiarezoodar.1@osu.edu, mao.64@osu.edu. Taylan Altan is professor and director of CPF, altan.1@osu.edu, www.cpforming.org, www.ercnsm.org.

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