Using limiting draw ratio to evaluate material drawability, Part II

FE simulation and prediction of fracture

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Editor's Note: This article is Part II of a two-part series. Part I, which appeared in the May/June issue, described the concept of LDR and the parameters that affect LDR tests.

LDR can be determined by experimental tests, analytical method, or finite element (FE) simulation. In LDR testing, the test conditions are not well-defined. Furthermore, the test is costly and time-consuming and often gives different results for one particular material because of variations in materials from batch to batch, in testing conditions, and in sheet thickness.

FE simulations help to determine the LDR with a reasonable accuracy in a shorter amount of time and at a lower cost compared to experiments. Moreover, with FE analysis, the effects of tool geometry, material properties, and testing conditions, such as coefficient of friction and blank holder force, can be determined more easily and simply than with experiments.

There is no reliable way to predict fracture from FE simulations. The forming limit curve (FLC) often is used to predict fracture, but FLC depends on strain path and cannot reliably predict fracture in complex forming processes. Moreover, obtaining the FLC for each alloy for different material batches and thicknesses requires a large number of experiments, so to predict fracture from FE simulations, a more accurate fracture criterion is required.

The Center for Precision Forming at The Ohio State University has investigated LDR test simulations for two different aluminum alloys, AA5754-O and AA6111-T4, comparing FE predictions with experimental results obtained by M. Jain and his colleagues.

FE Simulation Matrix and Tool Geometry

The tool geometry (see **Figure 1**) was modeled similar to that used in Jain's experiments. **Figure 2** lists the FE simulations conducted for the selected materials and blank diameters that result in different drawing ratios for each alloy. The maximum drawing ratio that can be achieved successfully without wrinkling or fracture determines the LDR.

A 60-kN blank holder force and 0.05 coefficient of friction were assumed, similar to conditions reported in the experiments. Material properties and flow stress data were obtained from the PAMSTAMP® database. The FLCs were obtained from Jain's study.

Simulation Results

The FE predictions were compared with experimental results for:

- Punch load versus displacement curve.
- Strain at different cup locations.
- Thickness distribution.

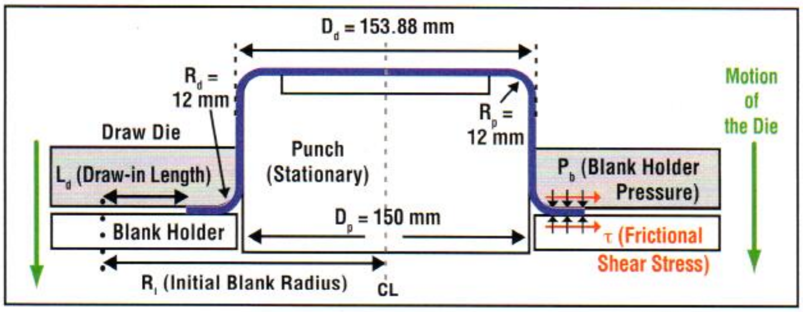

Figure 1

This schematic shows the tool geometry used for LDR testing and FE simulation.

Material	Blank Diameter (mm)	Drawing Ratio	Blank Holder Force (kN)	Coefficient of Friction
AA5754-O t_o = 1.55 mm	292.1	1.94	60	0.05
	311.2	2.07		
	317.5	2.11		
	323.9	2.16		
	330.2	2.20		
	336.6	2.24		
AA6111-T4 t_o = 1.55 mm	279.4	1.86	60	0.05
	304.8	2.03		
	311.2	2.07		
	317.5	2.11		
	323.9	2.16		
	330.2	2.20		

Figure 2

FE simulations conducted for AA5754-O and AA6111-T4 resulted in different drawing ratios for each alloy.

• Prediction of fracture using FLC.

When cups were formed successfully, calculated punch load versus displacement curves showed a good match with experiments. For drawing ratios at which fracture occurred, the calculated maximum force was similar to that observed in experiments. However, a sudden drop of punch force, when fracture was observed in experiments, could not be shown in simulations. Thus, a punch force versus displacement curve could not be used to predict the fracture and determine the LDR using FE simulations.

The prediction of fracture using FLC is illustrated in **Figure 3**. The plots show that the most critical area in the drawn cup in terms of fracture is around the punch corner radius. This is similar to what was observed in experiments. However, predicting fracture based on the FLC is still difficult, so a new criterion might be required to predict the fracture from the simulation results.

The CPF investigated the possibility of predicting fracture using the thinning rate (thinning versus stroke and time). Researchers found that in all cases thinning increased during the process. For drawing ratios in which the experiments showed that the cups were formed successfully, simulation results showed an almost linear increase in thinning. For drawing ratios with which fracture occurred, in a particular stroke position, a jump in thinning rate was observed. This may be caused by necking and initiation of fracture.

Figure 4 shows the LDR results for predicting fracture by using the thinning rate, based on the simulations and comparison with experiments. The table shows that simulation results using the thinning rate criterion are in good agreement with experiments. This method of predicting fracture using FE simulations appears to be promising. However, the method needs further investigation since, in this study, the stroke position where the sudden increase in thinning rate occurred in simulation is not the same as that observed in experiments.

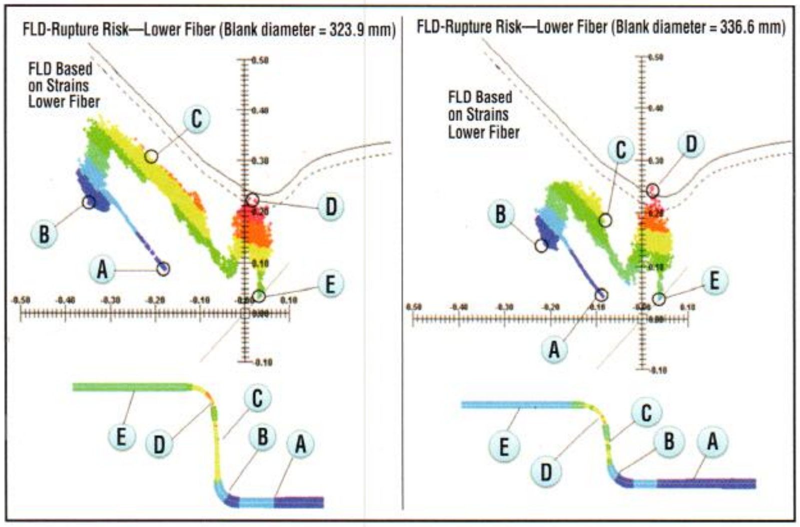

Figure 3

Shown here are the FLC and fracture risk for AA5754-O blanks with 323.9- and 336.6-mm diameters. The area of the cup shown by letter D is around the punch corner radius.

Material	Blank Diameter (mm)	Punch Stroke Where Fracture Is Predicted Based on Thinning Rate (mm), COF = 0.05	Punch Stroke Where Fracture Is Observed in Experiment (mm)	Error Between Simulation and Experiment (%)	Maximum Thinning in Fracture Stroke Based on Simulation (%)
AA6111-T4	279.4	No Fracture	No Fracture	—	—
	304.8	No Fracture	No Fracture	—	—
	311.2	No Fracture	No Fracture	—	—
	317.5	No Fracture	No Fracture	—	—
	323.9	50.37	53.14	5	10
	330.2	38.75	45.06	14	10
AA5754-O	292.1	No Fracture	No Fracture	—	—
	311.2	No Fracture	No Fracture	—	—
	317.5	No Fracture	No Fracture	—	—
	323.9	No Fracture	No Fracture	—	—
	330.2	57.75	43.45	32	13
	336.6	45.37	38.72	17	13

Figure 4

Simulation results were compared with experimental data obtained from Jain's study.

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References

M. Jain, J. Allin, and M.J. Bull, "Deep Drawing Characteristics of Automotive Aluminum Alloys," Materials Science and Engineering, *Vol. 256, No. 1-2 (1998).*

G.C.M. Reddy, P.V.R.R. Reddy, and T.A.J. Reddy, "Finite Element Analysis of the Effect of Coefficient of Friction on the Drawability," Tribology International, *Vol. 43, No. 5 (2010), pp. 1132-1137.*

G. Spampinato, H. Palaniswamy, and T. Altan, "Warm Deep Drawing of Round Cups from Mg, Al, and SS- Non-isothermal FE Simulations Using LSDYNA," CPF-1.1/06/03 (2006).