Use of FE Simulation and Servo Press Capabilities in Forming of AHSS and Aluminum Alloys

Ali Fallahiarezoodar, Long Ju, Taylan Altan

Center for Precision Forming, The Ohio State University, 1971 Neil Avenue, Office 339, Columbus, OH 43210 USA
fallahiarezoodar.64@osu.edu, ju.64@osu.edu, altan.1@osu.edu

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Abstract. Production of light weight and crash resistant vehicles require extensive use of AHSS (DP,TRIP,TWIP) and Al alloys to form complex shapes. This paper discusses practical determination of material properties and selection of lubricants for forming AHSS using a die set, designed for deep drawing. Tests were conducted in a 300 ton servo press. Thinning at the critical area of the formed part were measured and compared with FE simulation. Prediction of temperatures in deep drawing of selected DP steels and Al alloys in servo press is also discussed.

Introduction

Requirements for lightweight and crash resistant vehicle structures demand the use of high strength aluminum alloys and AHSS. These materials require advances in lubrication, die materials and coatings as well as new equipment. Die design for blanking and stamping of these alloys are routinely conducted by FE based process simulation that requires reliable input data, mainly in material properties and friction.

The flow stress data (true stress-true strain) of these alloys is best obtained by tests that emulate biaxial deformation conditions. Friction conditions are best determined using tests, such as the cup draw test, that represent the metal flow conditions encountered in stamping.

Servo drive presses used for sheet metal forming not only provide increase in flexibility and productivity, but also have the potential to improve formability in forming difficult to form alloys by optimizing the deformation speed and dwell at Bottom Dead Center (BDC) [1]. The effect of servo press in improving the forming quality by reducing the critical thinning and springback is investigated by various researchers.

Material properties and friction

In conducting FE simulation flow stress curve and coefficient of friction are very important to obtain accurate results. The die geometry can be accurately modeled by importing the 3D CAD model into FE software and adding necessary boundary conditions. Flow stress and coefficient of friction input, however, require experimental data.

The biaxial hydraulic bulge test is increasingly used to determine the flow stress, Fig. 1. At CPF, the bulge pressure is applied by a polymeric viscous material to avoid splashing oil when the specimen fractures at the apex. The flow stress of the sheet material can be obtained by measuring the bulge pressure and the bulge height and using inverse FE analysis [2,3]. The bulge height at fracture is an indication of material formability and can be used to evaluate the formability of various materials as well as that of the same material obtained from different batches and/or suppliers [3,4].

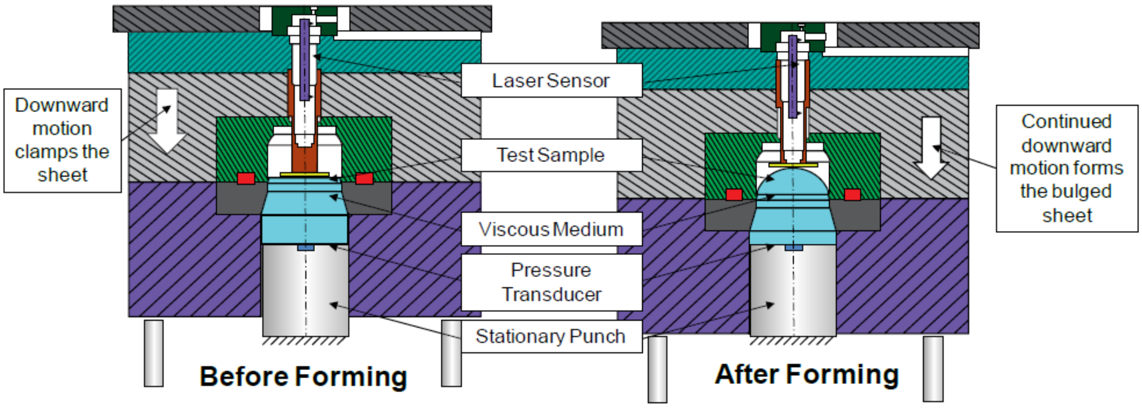


Figure 1: Viscous pressure Bulge Test. The flow stress is determined by inverse FE analysis using pressure and dome height measured during the test [4].

As seen in Fig. 2, the biaxial bulge test may provide flow stress up to 0.5-0.7 true strain while the flow stress, obtained from a tensile test, does not usually go further than 0.15 true strain values. Unrealistic flow stress data which is obtained from extrapolation of tensile data can affect the simulation results in terms of press force calculations, springback predictions, and thinning.

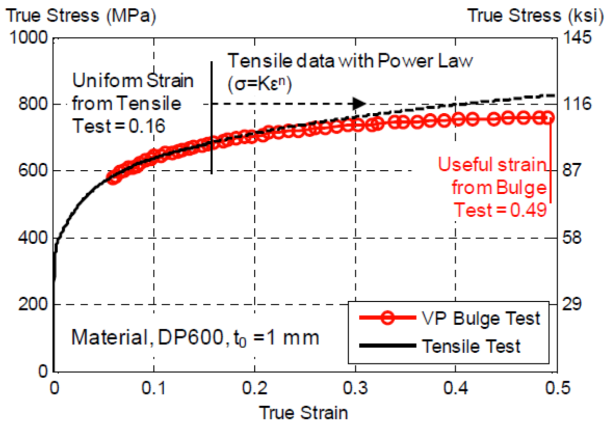


Figure 2: Comparison of flow stress determined by tensile test and bulge test for DP 600 steel [4].

In this study, the flow stress was determined using tensile and bulge tests, Fig. 1, for materials listed in Table 1, where the maximum true strains obtained in each test are also given.

Table 1: Sheet materials (Al 5182-0 and several AHSS) tested in this study to obtain flow stress (true stress-true strain) data [5,6]

Materials	Thickness(mm)	Max. strain in tensile test	Max. strain in bulge test
Al5182-O	1.2	0.2	0.5
DP 590	1.3	0.16	0.53
CP 800	1.4	0.07	0.3
DP 980	1.2,1.4	0.07	0.4-0.5
TWIP 900	1.1	0.4	0.65
TWIP 980	1.3	0.4	0.75
TRIP 1180	1.2	0.09	0.56

The Cup Draw Test, Fig 3, is used extensively to evaluate the performance of different lubricants and to determine the friction coefficient [5]. Several lubricants have been successfully tested with mild steels, AHSS and aluminum alloys [5,6]. In this test blanks with 305mm (12") diameter are drawn 80mm into a 152.8mm diameter die using a hydraulic press at ram speed of 40 mm/sec. The "average friction coefficient" is determined by comparing the perimeter of the flange obtained from experiment with simulation results.

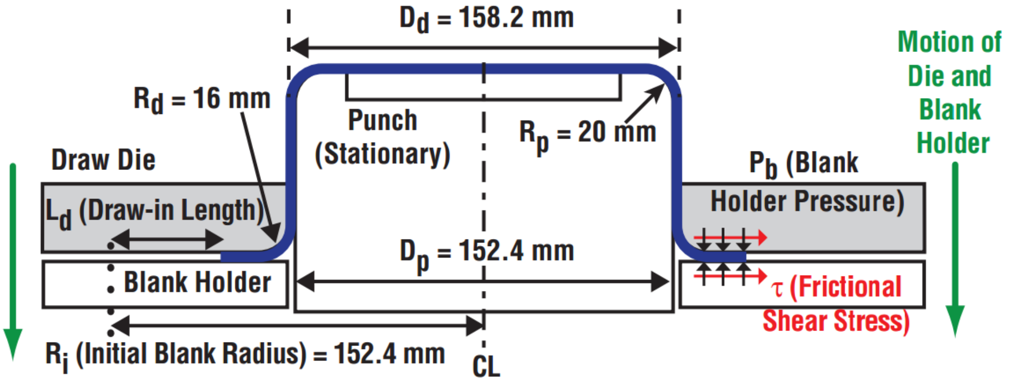


Figure 3: The schematic of the Cup Draw Test (CDT) to evaluate stamping lubricants [5]

Table 2 shows the test results for the evaluation of ten different lubricants, including dry and wet lubricants, for forming of AHSS materials. Results are compared with simulation for the prediction of the Coefficient of Friction (COF). Two DP 590 and DP 980 material were used for the lubrication test. All cups cracked before 80mm drawing when using lubricant C, F, G, and I. Therefore, it was not possible to determine the COF for these lubricants. Based on the results, lubricant H provides the best lubrication condition following lubricant B. However, it was very difficult to spread the lubricant H out on the sheet surface. Therefore, lubricant B with COF=0.09 was used in the deep drawing tryouts discussed in the next section of this study.

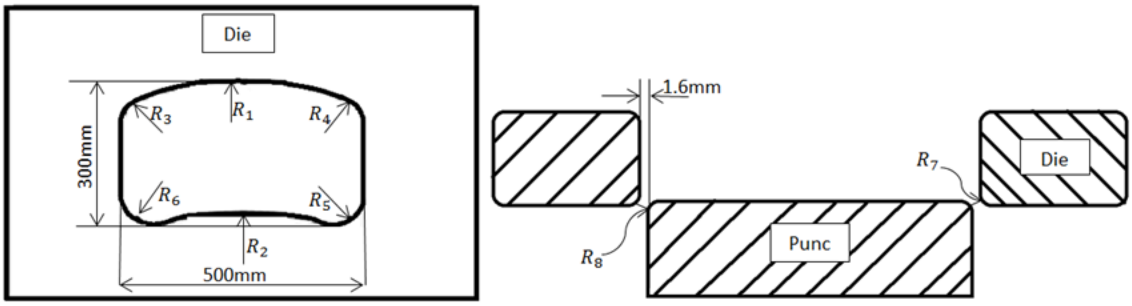
Table 2: Results of the lubrication tests for (DP 590 and DP 980)

Lubricant	Perimeter Rank	COF (calculated)	Observations/Notes
A	3/10	0.1 (DP980)	Was used as base, spread and formed well
B	2/10	0.09 (DP980)	Spread very well, seemed to be best lubricant
C	-	-	Did not spread well, beads up, cups fractured
D	6/10	0.09 (DP590)	Hard to spread, barely formed DP590
E	5/10	>0.1 (DP980)	Hard to spread out, formed DP590, barely formed DP980
F	-	-	Spreads, but then beads up, cups fractured
G	-	-	Spreads well, cups fractured
H	1/10	0.04 (DP980)	Very tacky, hard to spread, cups form very well
I	-	-	Dry film, cups fractured in punch radius
J	4/10	0.08 (DP980)	Thick, but spreads well, cups form well

Forming AHSS and aluminum in servo press

A 300 ton Aida servo drive press with 25 ton hydraulic CNC cushion has been used in this study. This press offers the flexibility of a hydraulic press (control of velocity in function of stroke position) with stroking rates that are higher than those found in mechanical presses of comparable load capacity. It is hypothesized that in addition to potential improvement in formability, the servo press may reduce springback by (1) dwelling at the Bottom Dead Center, and (2) re-striking motions.

Fig. 4. illustrates the schematic of the tooling built to investigate the formability of AHSS and Al alloys using a servo press. In the design phase, several "virtual tryouts" were conducted using the FE software PAMSTAMP for simulations.



Parameter	Notation	Value
Concave side radius	R_1	601.6mm
Convex side radius	R_2	598.4mm
Cavity corner radii	R_3	51.6mm
	R_4	56.6mm
	R_5	61.6mm
	R_6	66.6mm
Die-corner radius	R_7	10mm
Punch-corner radius	R_8	10mm

Figure 4: Die set used for deep drawing in the 300 ton servo press (originally designed to form AHSS) front and cross-section view [6].

In order to conduct the simulations the flow stress curve was obtained from the bulge test, Fig. 1, and the COF was determined using the combination of simulation and the CDT, Fig. 3.

Forming of Al 5182-0 in the Servo Press

Fig. 5 shows the actual formed part at 75 mm draw depth and the simulation results of drawing Al 5182-0. The thinning in the drawn part at the critical corner area is shown in Fig. 6. This figure also illustrates how the COF and the source of the flow stress data (tensile or bulge) affect the simulation results. It is seen that the simulation results, obtained using the bulge test data are closer to experimental thinning measurements.

There are experimental observations indicating that ram deceleration, cushion pre-acceleration and reduced forming speed in servo presses can reduce impact shock and improve formability. This can be explained by better lubrication (less splash of lubricants thanks to softer impact) and lower temperatures of the blank (slower speed at the sheet/die interface).

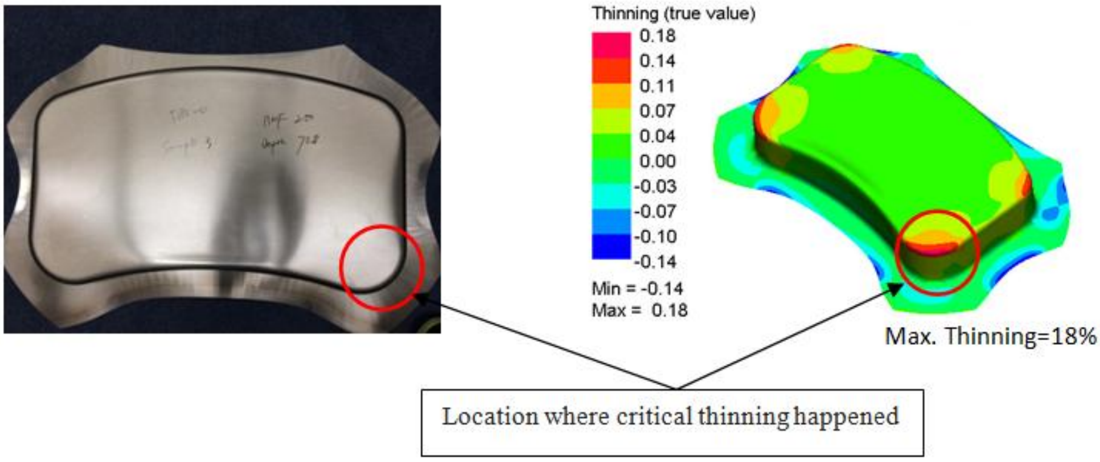


Figure 5: Aluminum panel formed by 300 Ton servo drive press and simulation results of the same operation

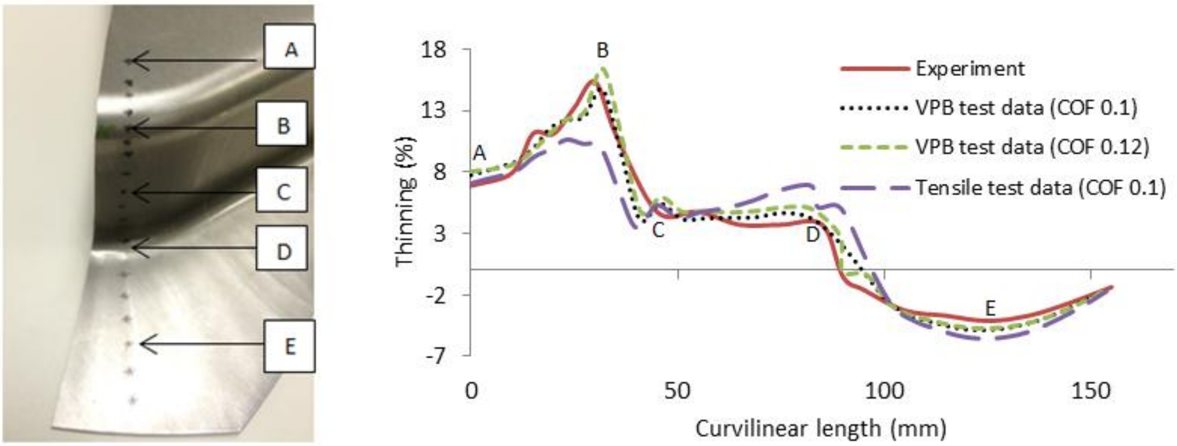


Figure 6: Comparison of measured and predicted thinning at the critical corner of the drawn part (Material: Al 5182-0, thickness = 1.2 mm, BHF = 150 ton, COF = 0.1 and 0.12, Draw Depth = 75 mm, Ram speed = 310 to 0 mm/s)

Non-isothermal simulations conducted in FEA software package (PAMSTAMP) allows the calculations of heat generation in the deformed part and heat transfer between part and tools. As seen in Fig. 7, temperatures of about 80℃ could be reached in the present drawing conditions. The important parameters used in the prediction of temperatures are summarized in Table 3.

Table 3: Thermal and mechanical properties used for the non-isothermal simulations of Al 5182-0 [7]

Property	Description
Flow stress curve	Bulge test data
Young's modulus (E)	70.6 GPa
Poisson ratio (υ)	0.341
Coefficient of friction (COF)	0.08~0.14
Thermal conductivity (λ)	130 W/m·C
Specific heat capacity (C)	900 J/kg·C
Initial temperature	20℃

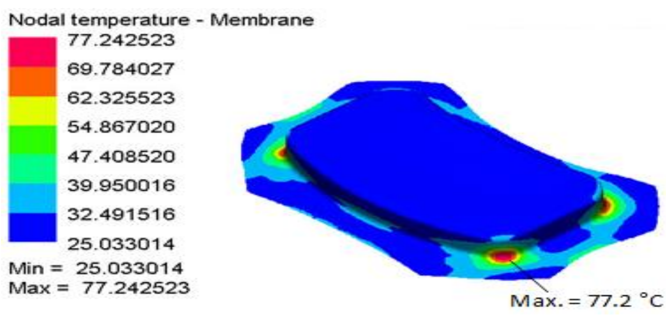


Figure 7: Temperature predictions during drawing of Al 5182-O (PAMSTAMP). Maximum temperature at the part corner is about 80°C.

Fig. 8 illustrates the effect of coefficient of friction (COF) upon the calculated force-stroke curve, in comparison with measurements. The COF of friction, used in initial simulations was COF = 0.08 and was obtained from CDT, conducted in a hydraulic press with a ram speed of 40 mm/sec. In the servo press trials, however, the ram speed changed from 75 to 310 mm/sec during deformation. As a result, also seen in Fig. 8, the value of COF must be larger so that measured and calculated load-stroke curves match.

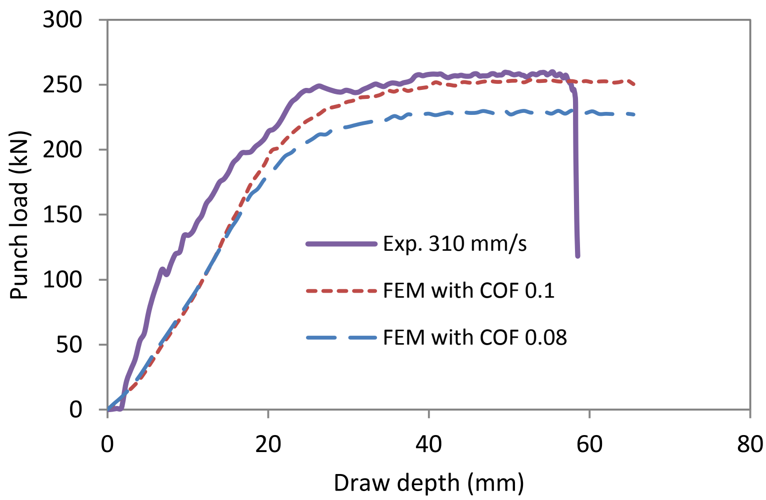


Figure 8: Comparison of the load versus stroke curve measured from experiment (solid line) and FE prediction with two different COF, in forming Al 5182-0.

Forming of AHSS in Servo Press

CPF has been investigating the possibility to form complex AHSS parts with tight tolerances (i.e. reduced or controllable springback) using servo presses. An earlier study together with PtU (University of Darmstadt) showed that controlling the speed does affect the thinning distribution in deep drawing of DP 600 [8]. Recently, together with a servo press manufacturer, an OEM and a first tier part supplier, CPF designed a new die set for forming several AHSS grades in a 300 ton servo press, Fig. 4. The die and blank holder are made up of multiple inserts, while the punch is in one piece, to allow for varying tooling dimensions (corner radii) and tooling material/coatings. The specific shape of the die allows performing of different forming operations such as deep drawing, U-bending, shrink and stretch flanging, and hat bending. Studies on thinning, heat generation during forming, and spring back are in progress. The preliminary results of forming and heat generation studies are summarized in the current study.

FE simulations are conducted to investigate the ability of predicting the tool and specimen temperatures, as well as the thinning during the forming process for several AHSS, Table 1. As an example, preliminary results given in Fig. 9, show a temperature increase up to 200°C for DP980 with 1.2mm thickness, around the corner of the formed part after 55mm punch stroke (draw depth). The predicted temperature increases may not be quite accurate since the thermal parameters are based on the low carbon steel and tool steel parameter for blank and tools respectively. The summary of the thermal properties can be found in previous studies [9,10].

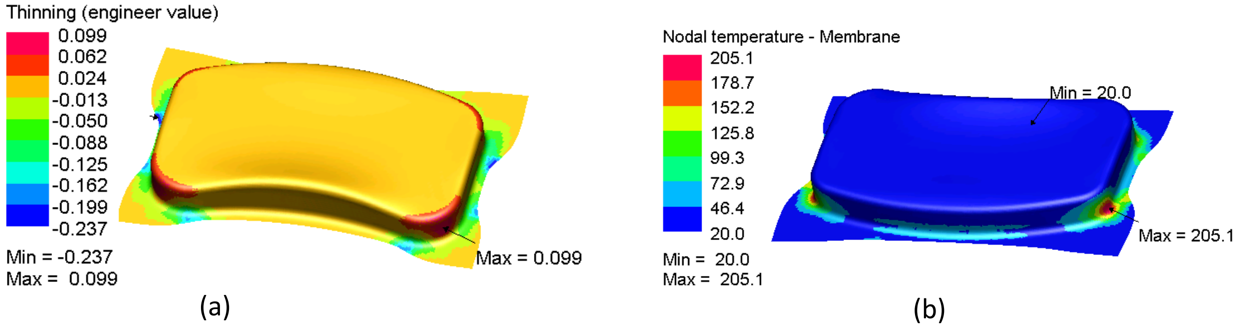


Figure 9: (a) Thinning and (b) Temperature predictions for 55mm deep drawn DP980 sheet with 1.2mm thickness (PAMSTAMP)

Table 4, summarizes the maximum press load obtained from the experiment and the comparison with simulation results with different COF. Similar to deep drawing Al 5182-O, the maximum ram force predicted from the simulation does not agree with the experimental results when assuming the COF=0.09 that is obtained from the CDT test. However, COF=0.12 provides the simulation results with maximum ram force similar to what is measured from the experiment. This observation shows that the higher forming speed of the servo press, compared to what was used in CDT using the hydraulic press, affects the lubrication performance and results in increase in COF.

Table 4: Comparison of the maximum ram force value obtained from the experiment with those predicted by FE simulation with two different COF.

Material	Drawing Depth (mm)	Max Total Ram Force (KN)	Max Total Ram Force, simulation with COF=0.09 (KN)	Max Total Ram Force, simulation with COF=0.12, (KN)
DP590 (1.3mm)	70	737	677	724
CP800 (1.4mm)	50	838	792	842
DP980 (1.2mm)	55	874	815	871
TWIP900 (1.2mm)	70	719	652	695
TWIP980 (1.3mm)	70	815	744	794
TRIP1180 (1.2mm)	48	894	839	909

Summary and conclusions

Results of this study have shown that the biaxial bulge test can provide flow stress data up to higher range of strains compared to the conventional tensile test for both aluminum and AHSS materials. The CDT was used as the lubrication test to evaluate different lubricants for forming aluminum and AHSS. The coefficient of friction was determined using the CDT test data and comparison with simulation results. Deep drawing of aluminum and several different AHSS materials were conducted using 300 ton servo drive press and a specially designed die. FE Simulations were conducted in designing the die and predicting metal flow and sheet thinning during the tests. Comparison of the simulation results with experiments have shown that the friction condition is different in deep drawing in the servo press compared to the CDT obtained in a hydraulic press. Non-isothermal simulation of the process also shows that the temperature increases during the forming of the material. This increase of temperature can influence the sheet formability and the lubrication performance and consequently affect the tool wear.

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