Applications of FE Simulation for Stamping and Blanking of Sheet Materials

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Abstract

Production of light weight and crash resistant vehicles requires extensive use of AHSS (DP, TRIP, TWIP) and Al alloys to form complex shapes. This paper discusses the practical determination of material properties and evaluation of lubricants for establishing optimum conditions for stamping these materials. The emphasis is on practical use of FE simulations and includes: 1) determination of material properties and friction, 2) application of servo drive presses to improve formability in forming of AHSS and Al alloys, 3) FE simulation of hot stamping to obtain tailored properties, 4) predicting the pierced/blanked edge quality and its effects on fracture limits in flanging, and 5) predicting onset of necking and fracture by using FE simulations.

1 Introduction

The automotive industry is increasingly using hot pressed boron steels and advanced high-strength steels (AHSS) (DP 600 to DP 1400), as well as transformation-induced plasticity (TRIP), martensitic (MS), and twinning-induced plasticity (TWIP) steels. Thus, new or improved methods are necessary to characterize materials and to select lubricants and advanced forming machines.

2 Material Properties and Friction

In FE simulations, the accuracy of the input data, i.e, flow stress curve and friction, are very important to obtain accurate results. The die geometry can be easily modelled by importing the 3D CAD model into FE software and adding necessary boundary conditions. Flow stress and friction input, however, require experimental data.

2.1 Uniaxial Flow Stress Determination – Tensile Test

Typically, flow stress (true stress-true strain) is determined by the well-established, uniaxial standard tensile test that gives the values of yield and ultimate tensile stresses as well as uniform and total elongations and anisotropy coefficients. The tensile flow stress data can be obtained usually until 0.10-0.30 true strain. In most sheet metal forming operations, however, effective strain levels are higher than this value. Thus, the tensile data is usually extrapolated in conducting simulations, resulting in possible errors.

2.2 Biaxial Flow Stress Determination – Bulge Test

The biaxial hydraulic bulge test is increasingly used to determine the flow stress. While most R&D groups utilize an Image Correlation System (ICS), the simpler and practical bulge test using a polymeric pressure medium, is also shown to provide similar results, Figure 1. Using the measured forming pressure and the bulge height it is possible to determine the flow stress of the sheet material by means of inverse analysis. Furthermore, the bulge height at fracture is an indication of material formability [1].

The bulge test may give flow stress data up to 0.5-0.7 true strain. Thus, the need for extrapolation using a curve fit and resulting errors are reduced. An example is illustrated in Figure 2, where the flow stress obtained from the bulge test is about 10% lower than the extrapolated values at 0,5 strain. The error in the flow stress would affect the predictions of a) the press force b) springback, and c) thinning since the strain hardening is not considered accurately.

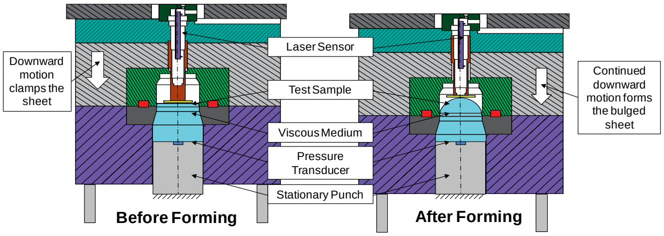


Figure 1: Viscous Pressure Bulge Test. The flow stress is determined by inverse FE analysis using pressure and dome height measured during the test [1].

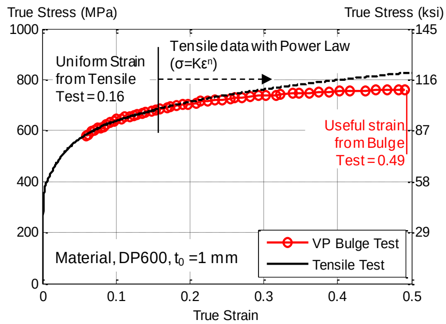


Figure 2: Example comparison of flow stress determined by tensile test and bulge test.

2.3 Biaxial Flow Stress Determination – Dome Test

Work is also in progress in developing an analysis to expand the application of the well-known Limited Dome Height (LDH) test to obtain biaxial flow stress data, Figure 3.

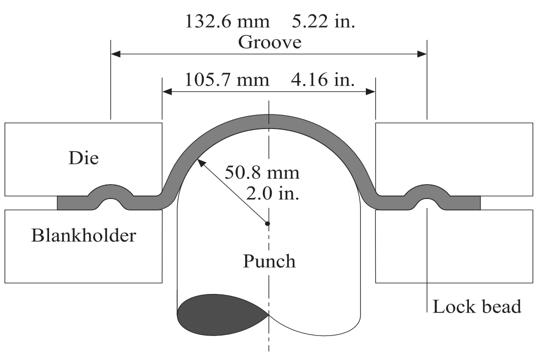


Figure 3: Schematic of the Dome Test. “Optimum” lubrication used between sheet and punch, allows “frictionless” deformation [3].

In this application, the dome height (or punch stroke) and the deformation force, measured during the test, are used to obtain the flow stress curve, using FE based inverse analysis [2]. Assuming material follows Hollomon’s law (Eq.1), where K is strength coefficient and n is strain hardening exponent. The procedure is described below:

- Perform LDH test and record force- punch stroke data during experiment
- Conduct FE simulations under the same conditions with the initial guess of K (1000MPa) and n (n=0.06 to 0.6)
- Calculate force and punch stroke curves and determine the n values
- Calculate K values.

$$\sigma = K\epsilon^n \quad \text{Eq.1}$$

Based on the above mentioned procedure, a computer program, PRODOME was developed using MATLAB. By running PRODOME, K & n values can be determined. This method can also be used to determine a flow stress equation with n values, varying with strain.

2.4 Friction Coefficient

In most FE simulations, the friction coefficient (μ) is considered to be constant. However, in reality it depends on the surface roughness and coating of the sheet and tool material, contact pressure, sliding speed, lubrication, and temperature of the sliding surface [3]. Thus, to determine the friction coefficient a test is needed that can emulate the pressure, speed and lubrication at the interface as close as possible to production conditions.

The cup draw test has been shown to be very useful to determine the friction coefficient. Several lubricants have been successfully tested with mild steels, AHSS and aluminum alloys [4]. In this test, Figure 4, 305 mm (12") diameter blanks are drawn in a hydraulic press to 80 mm (3.2") depth. Thus, lubricants can be evaluated in the deep drawing by (i) measuring the maximum applicable blank holder force without failure in the cup wall and (ii) measuring the perimeter of the cups formed using different lubricants at the same blank holder force [5].

The "average friction coefficient" is calculated by using FE simulations and inverse analysis.

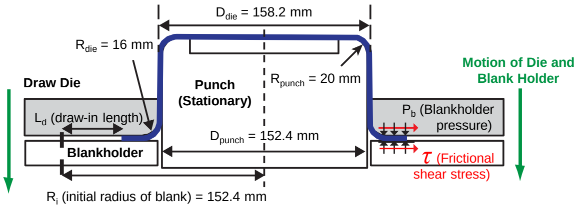


Figure 4: Schematic of the Cup Draw Test [4].

3 Forming AHSS and Aluminum in servo press

3.1 Servo Presses

Servo drive presses are more increasingly used in automotive industry and offer the flexibility of hydraulic presses (precise control of velocity and stroke motion), with stroking rates that are higher than that of mechanical presses.

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 in sheet/die interface). Temperature may 1) increase friction and 2) decrease flow stress – thus may affect the initiation of local necking. Preliminary simulations have shown that sheet/die interface temperatures around or above 100°C (>210°F) are common in forming of high strength steels, Figure 5. If the effect of press motion on formability can be better understood, this can help forming “difficult-to-form materials” such as aluminium alloys and advanced high strength steels (AHSS).

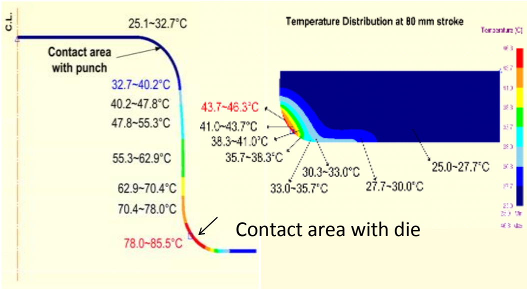


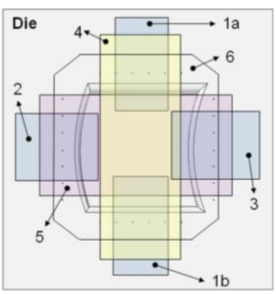
Figure 5: Temperatures in deep drawing of DP590 (Deform 2D) [5].

In addition to improved formability, the free-motion of servo-press may also reduce springback by, 1) dwelling at the bottom, 2) bottoming and/or 3) re-striking motions. Experimental evidence shows that these motions reduce springback in bending AHSS.

Furthermore, accurate control of ram position and speed has been shown to improve the blanking conditions by reducing noise, vibrations, reverse loading and tool wear [7].

3.2 Forming of AHSS in Servo Press

Work is in progress to investigate the potential advantages of forming complex AHSS parts with tight tolerances (i.e. reduced or controllable springback) using servo presses. An earlier study, conducted at PtU (University of Darmstadt) showed that controlling the punch speed does affect the thinning distribution in deep drawing of DP 600 [7]. In cooperation with a servo press manufacturer, an OEM and a first tier part supplier, A new die set is designed for forming several AHSS, Figure 6.



Blank geometries for:

1. Straight flanging
2. Stretch flanging
3. Shrink flanging
4. U – channel drawing and U – bending
5. Curved U – channel forming
6. Deep drawing

Figure 6: Die design (top view) concept to test different springback conditions in forming AHSS in a servo press.

4 Hot Stamping of Boron Steels

Direct and Indirect hot stamping of Mn-B steels are well known and practiced in industry, Figure 7. However, parts with high strength properties are difficult to weld or join and they may not provide sufficient toughness to absorb crash energy.

Therefore, techniques have been developed to obtain tailored properties in a given part by using (a) Tailored Welded Blanks (TWB), (b) Tailored Rolled Blanks, or (c) by controlling the microstructure variation at various locations in the part during quenching [8].

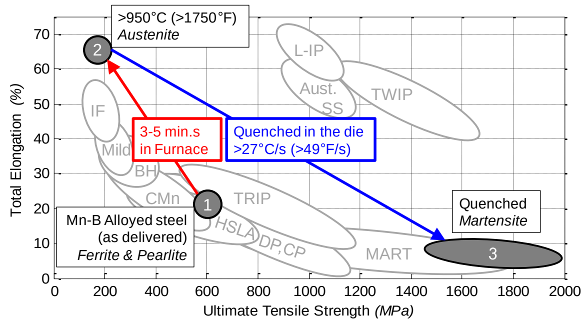


Figure 7: Schematic illustration of microstructure changes in hot stamping.

4.1 Forming Simulations

Simulation of the first 3 stages (gravity, clamping, forming) of the hot stamping process is used to predict potential failures (cracks, wrinkles) in the hot formed part. An example is seen in Figure 8.

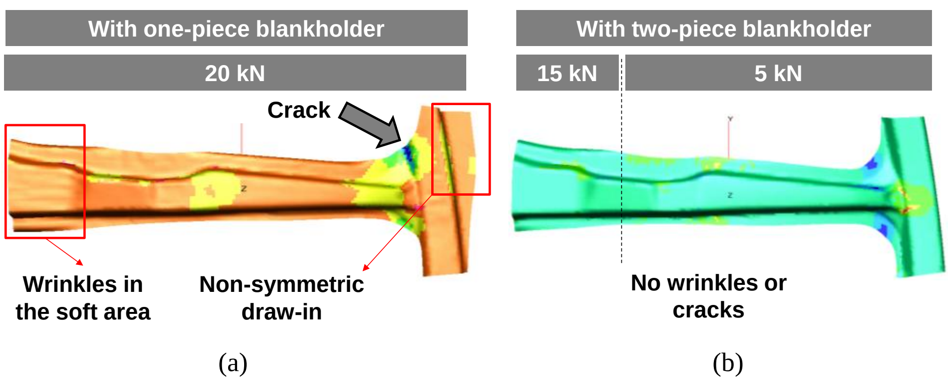
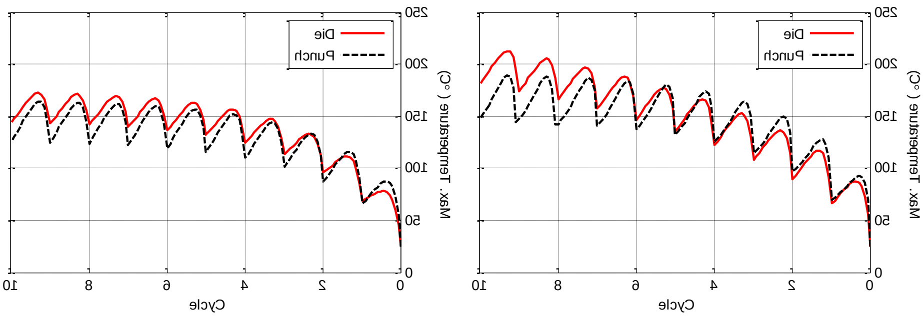


Figure 8: Tailored B-pillar forming simulation: (a) conventional blankholder concept, (b) two-piece blankholder concept.

4.2 Quenching Simulations

Once the part is successfully formed, it is then quenched (held under pressure between cooler die halves) to obtain the final microstructure, hardness and strength. In this stage, the die halves are pressed together with a constant force. Several methods of simulation were developed to design quenching stage process parameters, such as: 1) duration of quenching stage, 2) number, diameter and location of cooling channels, and 3) number, power and location of heating cartridges (in case of parts with tailored properties).

To ensure the cooling channels are designed properly for a robust production, a cyclic quenching analysis is required, Figure 9. Using FE simulations, location, number and diameter of cooling channels can be optimized. Furthermore, the flow rate in the channels can be determined for a robust process.

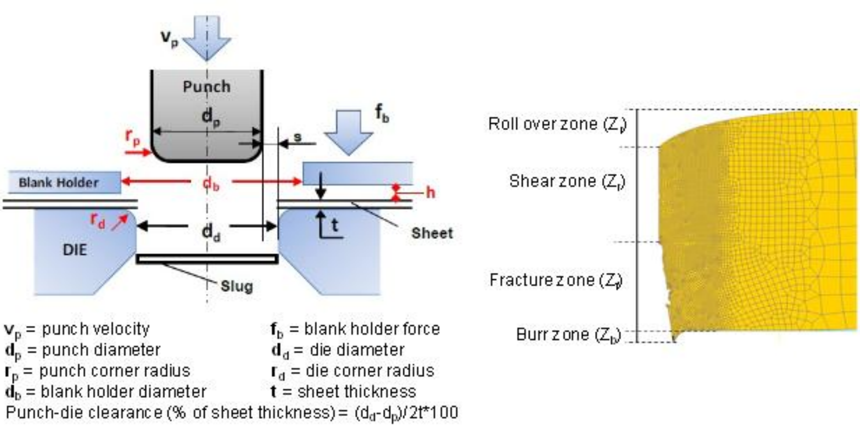


(a) (b)

Figure 9: Cyclic quenching simulation with: (a) low flow rate, and (b) high flow rate in cooling channels.

5 Blanking / Piercing / Hole Flanging

Edge cracking in hole flanging is a major concern in forming AHSS and is mainly affected by the edge quality in the original blanked hole. The edge quality of the blanked or pierced hole is determined by: a) punch/die clearance, b) blank holder (stripper) pressure near the sheared edge, c) punch geometry, and d) punch velocity, Figure 10.

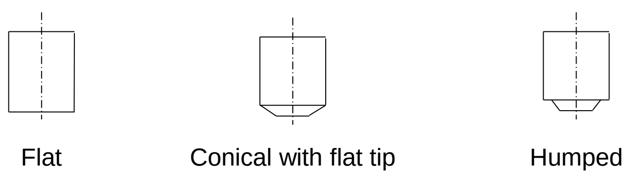


(a) (b)

Figure 10: (a) Schematic of blanking, (b) blanked edge (as obtained from FE simulation).

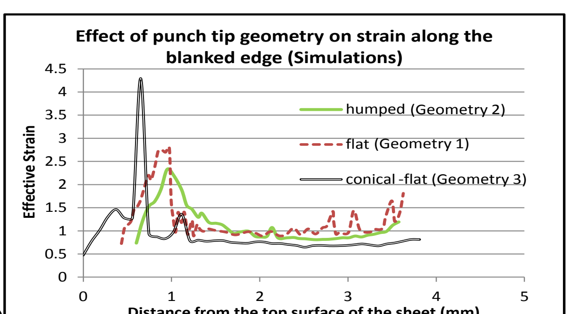
FE simulation of the blanking operation, although somewhat approximate, gives useful information about the process and on how best to select the process parameters. Modifications of the punch/die clearance at the corners, in punching a square hole, showed that stresses at the punch corner can be reduced and punch life can be increased. Investigation of high speed blanking of electronics parts also illustrated that increasing the blank holder pressure near the edge, improves the quality of the sheared surface [9]. This effect is also well known from the application of fine blanking.

The punch shape affects (a) the stresses during blanking and (b) the resulting strain distribution, as a result the quality, at the blanked edge, Figure 11. Estimation of temperatures and strains at the sheared edge, compared with available experimental data [10], help to illustrate how best to select the process variables to improve the quality of the blanked edge and to increase the hole expansion ratio as shown in Figure 12.



(a) (b) (c)

Figure 11: Punch tip geometries investigated to determine the strains at the shear edge and their effect upon flanging (a) flat tip, (b) conical with flat tip, (c) humped tip.



(a)

(b)

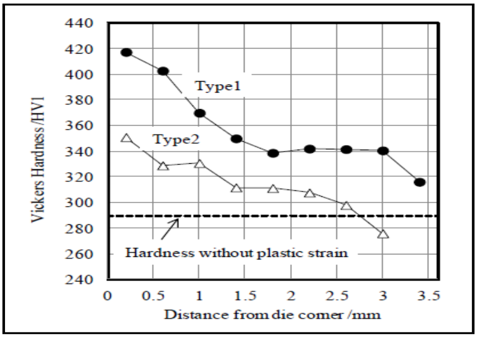


Figure 12: Effect of punch tip geometry on edge quality (a) Simulations (b) Experiments from [10] Note: Type 1 denotes flat bottom punch and type 2 denotes humped bottom punch.

6 Necking and Fracture Prediction

In sheet metal forming simulations, the onset of fracture or localized necking is usually predicted by Forming Limit Diagrams (FLDs). That are expensive to obtain doe each batch of sheet material. This method is strain-path dependent and has limited application in:

1) Multi-stage forming operations where the strain path is always non-linear,
2) Advanced high strength steels with more than one phase (DP, TRIP, TWIP, etc).

Therefore, for sheet metal forming simulations, a new and practical fracture criterion is required, which is independent from the strain history and easy to compute in simulation. The following options are being investigated:

1) Variation of thinning rate, and
2) Variation of strain rate (equivalent and/or principal).

The objective of the ongoing study is to attempt to predict fracture in sheet forming by examining the maximum thinning variation in the part, during FE simulation. Thus, simulations and their comparisons with experiments are being conducted in:

a) tensile tests (sheet specimens),
b) bulge tests,
c) dome tests, with and without lubrication (LDH tests) ,
d) cup draw test with various lubricants,
e) forming of practical automotive stampings from Al alloys and AHSS.

Preliminary simulations of tensile test and limiting dome test have shown that the thinning rate could be used to estimate the onset of necking, Figure 13. Volk and Hora [11] have shown the “characteristic point” where thickness strain increases dramatically, could be calculated to predict the onset of necking, as applied to the tensile test simulations, Figure 13.

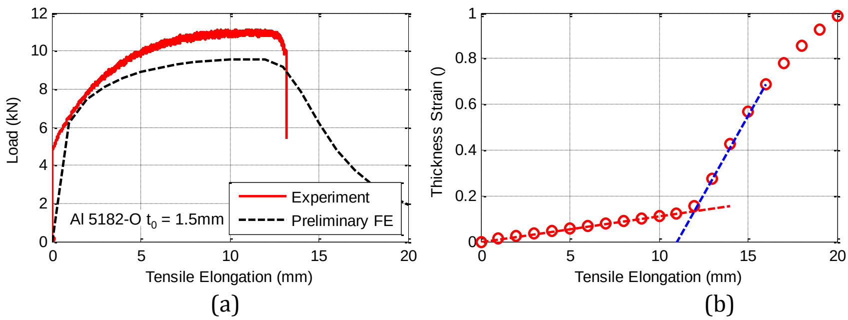


Figure 13: Preliminary tensile test simulations show that necking can be predicted:
(a) by comparing load-elongation curves, and (b) by finding the characteristic point.

This technique has also been tested using cup drawing experiments. Both DEFORM 2D and PAMSTAMP simulations have shown that the method can be used to predict the onset of necking and cracking in deep drawing of stainless steel 304 as observed in the experiments [12], Figure 14. This criterion will be further tested in complex forming operations.

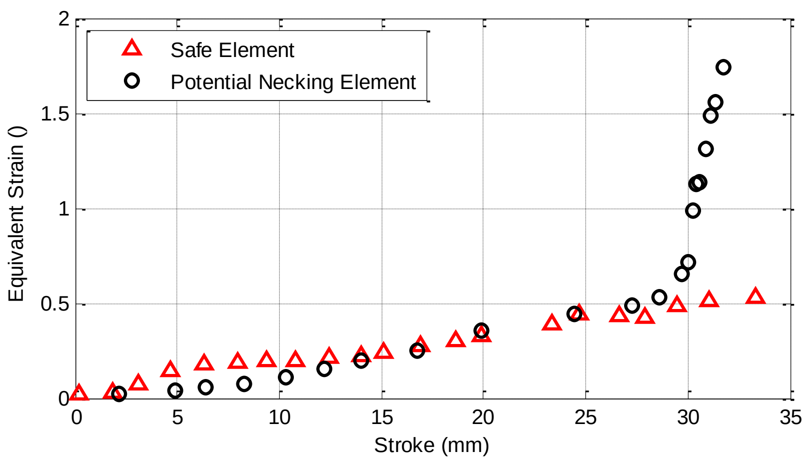


Figure 14: Evaluation of strain vs. stroke in the simulation of deep drawing of SS 304 [13].

7 Summary and Conclusions

The state of technology and the trends in transportation industry can be summarized as follows [14]:

1) Requirements for lightweight and crash resistant vehicle structures demand the use of high strength aluminium alloys and AHSS.
2) To obtain reliable input data for FE simulations, it is preferable to use bulge test for obtaining the flow stress and the cup dome test for evaluation of friction.
3) Servo drive presses used for sheet metal forming do not only provide increase in flexibility and productivity, but have also the potential to improve formability in forming difficult to form alloys by optimizing the deformation speed and dwell at BDC.
4) Advances in simulation software, when used appropriately with the necessary input data, allow non-isothermal simulation of stamping operations such as hot stamping (press hardening) of steels and warm forming of aluminium alloys.
5) Simulation of blanking operations offer the potential to understand the effects of material and process variables upon the quality of the sheared edge as well as in reducing edge cracking in bending and hole flanging.
6) The prediction of the maximum thinning during forming, in function of time or punch stroke, may represent a practical and simple method for predicting fracture in AHSS. These methods may be more easily applied in practice than the commonly used fracture prediction, based on FLDs.
7) R&D in all these topics, listed above, is being conducted by many researchers, especially in forming ultra high strength steels that have limited formability and are prone to edge cracking.

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