Comparison of Single Point Incremental Forming and Conventional Stamping Simulation

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Abstract

This paper resumes simulation related aspects of one project aimed to compare two different sheet metal manufacturing technologies: Incremental Sheet Forming (ISF) and Conventional Stamping. Simulation of stamping in different stages of product development is an established practice in the industry, and the obtained results utilized to validate the process engineering before engaging in tooling fabrication. On the other hand, ISF simulations are difficult to implement, mainly due to its long computational time stemming from the incremental and localized deformation strategy, which for a simple part demands a tool path length in the order of hundreds or thousands of meters.

The component under study is a square pyramid frustum formed with Stamping and ISF. A comparison of numerical and experimental results of both manufacturing methods is provided. Results indicate that the simple material model and the overall modelling approach used to simulate both processes, using the explicit LS-DYNA® solver, give valuable information for process design and improvement, maintaining an affordable computational time. In the case of stamping, the need to implement drawbeads to avoid sheet wrinkling was identified. For ISF, improvements to the final geometry, either based on the addition of a 3D printed die or tool-path modification were identified.

Keywords: Incremental sheet forming, Explicit analysis, Stamping, ISF

Introduction

Given the importance of stamping technologies in Mexico´s metal manufacturing industry, the Universidad de las Americas Puebla fosters the development of skills related to this field among its mechanical engineering undergraduate students. Therefore, a one semester course named “Selected Topics: Simulation of sheet metal forming” is offered to senior students. In parallel, a research group works on different aspects of metal forming like characterization, tool design and manufacturing and simulation. In both the course and research activities, LS-DYNA is used as the simulation tool.

From the vast family of processing operations, shaping, or deformation processes, produce one final product by the application of forces beyond the yield limit of the material. The processes under study, Stamping and Incremental Sheet Forming, belong to the sheet metal processes. Each has its own characteristics but both depend on the deformation caused by the tool on the blank in order to get a final product.

In the automotive industry, the production of sheet metal parts is dominated by conventional (pressing) stamping processes. Deep drawing is a very cost-effective and well-established process for the mass production of sheet metal components. However, due to the high costs and prolonged manufacturing time for die manufacturing, it is not suitable for small batch productions in a short time period. ISF may be implemented in the early stages of product development for Rapid Prototyping of parts complying with the fit and form requirements of the final product.

Four basic components of the ISF process are: 1) A forming machine capable to execute a movement sequence programmed in a Computer Numerical Control (CNC) unit. 2) A blank or sheet material to be formed. 3) A

solid forming tool of small dimensions relative to the blank, which in most of the cases has a hemi-spherical shape. 4) And a blank-holder or clamping support for the blank.
The belief that ISF is better than conventional stamping for low production has not been evaluated in a back to back comparison: manufacturing the same part using the two processes. This paper resumes the simulation aspects of a project aimed to compare the two mentioned technologies.

Simulation State of the Art

As the physical operation, simulation of stamping in different stages of product development is a common practice in the industry, and the obtained results are utilized to validate the process engineering before engaging in tooling fabrication. A quick search at the Dynalook website gives more than 200 results from the "sheet metal stamping" keywords. In contrast, SPIF simulation has only one previous presentation in LS-DYNA conferences [1]. For both processes, a chronological review shows that from the earliest attempts, the aim for reduction of the computational time has biased the numerical set-up to explicit time integration and shell elements, two reliable components of the LS-DYNA solver.
Since the physical time of a standard forming process is excessively long for the time increment computed with Equation 1[1], it is common to use an artificial increment of a) the tools speed (tool velocity scaling), and b) the material density (mass scaling).

$$\Delta t \le \frac{L}{\sqrt{E/\rho}} \tag{1}$$

In the case of ISF simulations, the incremental tool-path strategy, which for a simple part demands a tool path length in the order of hundreds or thousands of meters, adds further complication to the nonlinear behavior encountered in the simulation of conventional forming processes. As a consequence, solution time of days or even weeks has been reported, for example by Taleb-Araghi et al. [2], even for the simulation of simple parts[2].

Methodology

Part Geometry and Material

The analyzed part is a square pyramidal frustum, with a base length of 70 mm, the angle of the pyramid sides with the original blank is 45° and its height is 20 mm (Figure 1). The blank geometry is a square sheet of 100x100 mm made with 0.5 mm thick AISI-304 steel.

Table 1. Properties of the AISI-304 stainless steel.

Density (ton/mm3)	Young Modulus (MPa)	Poisson's ratio	σ_Y (MPa)	σ_U (MPa)	K (MPa)	n
7.830e-9	207000	0.300	269	669	1332	0.395

[1] $\Delta t \sim 2e\text{-}7$ s, with an element length, L=1 mm; steel Young modulus, E=200000 MPa; steel density, ρ=7.83e-9 ton/mm^3
[2] The previous discussion involves only the forming stage. For the springback simulation, treated as a static stress relaxation problem, the implicit algorithm is without question the best option [4, Maker and Zhu, 2001).

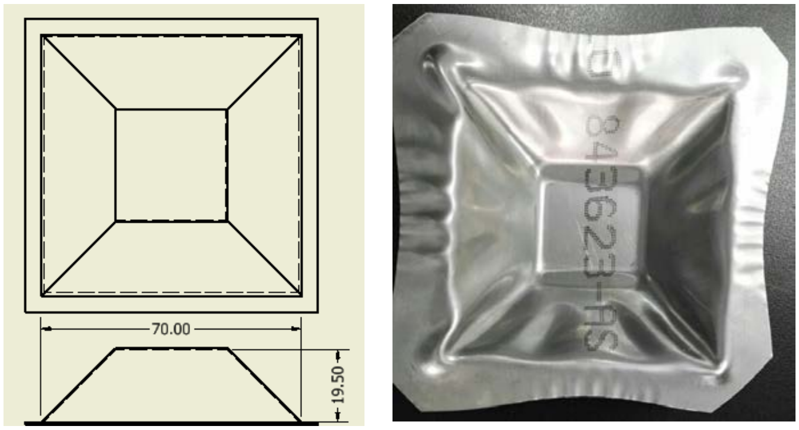

Figure 1. (Left) Drawing, not to scale, of the studied component, and (right) picture of one stamped part without drawbeads.

Simulation Generalities

The numerical models were solved with the explicit solver of LS-DYNA, release 971, running on a 4-core Windows® PC. The mid surface of the blank was described by a regular mesh of fully integrated linear quadrilateral shell elements (*SECTION_SHELL, ELFORM=16) using 5 integration points thickness-wise. Based on the results of a convergence study, square elements of size 1.5 mm x 1.5 mm were utilized for the blank. Symmetry simplification was not applied. Surface to surface frictional contact (μ=0.1) was defined between tools and blank. Tool velocity and mass density were scaled. External surfaces of the forming tools were meshed with shell elements in combination with a rigid material defined with steel properties. Plasticity was modelled with the isotropic von Mises yield criteria and the Hollomon hardening rule. Therefore, the material properties summarized in Table 1 were utilized within the *MAT_POWER_LAW_PLASTICITY model.

ISF Simulation

While arbitrary geometry parts require a CAM generated tool-path, the basic shape formed in this investigation utilized a Python language routine capable of generating the tool-path for conical and pyramidal frusta with straight or curved walls. A second routine translated the CNC commands to velocity curves in the X,Y and Z directions. To represent the clamping conditions, the degrees of freedom of the nodes defining the perimeter of the blank were fixed. Finally, physical rotation of the tool was ignored for the simulation.

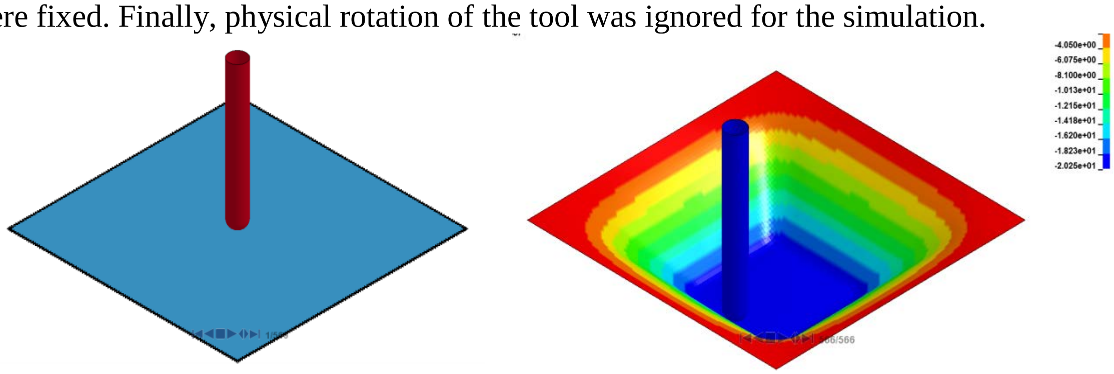

Figure 2. (Left) Initial ISF model, and (right) final deformation state.

Stamping Simulation

The upper and lower binder were generated with Creo Parametric 4.0, exported in STEP format to LS-PrePost 4.5 (LSPP) and set in their final position, holding the blank. The binders have a centered square hole of 80x80 mm, with round corners of 10 mm, to permit the engagement of punch and die. The two forming dies were scanned with one GOM ATOS equipment. The point clouds given by the scanner were in STL format which allowed them to be imported in LSPP and used in the simulation without any remeshing (Figure 3). The final assembly was done in LSPP, setting the binders and the lower die as rigid static parts and the upper die (punch) as the travelling rigid part (Figure 4).

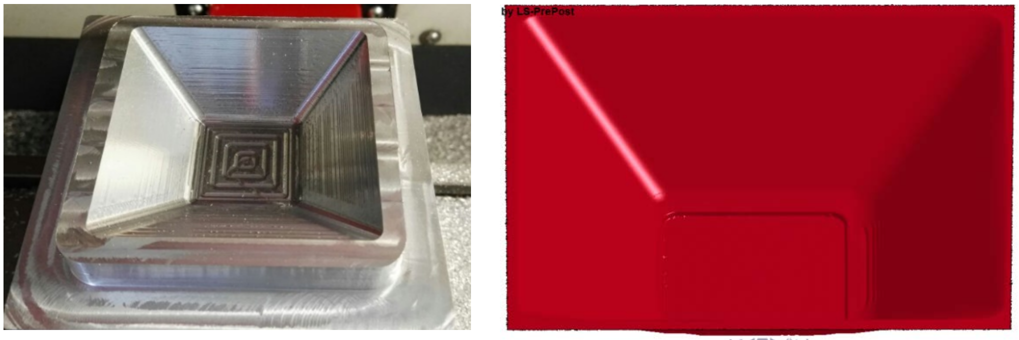

Figure 3. Physical die (left) and its digitized 3D model (right) imported in LSPP.

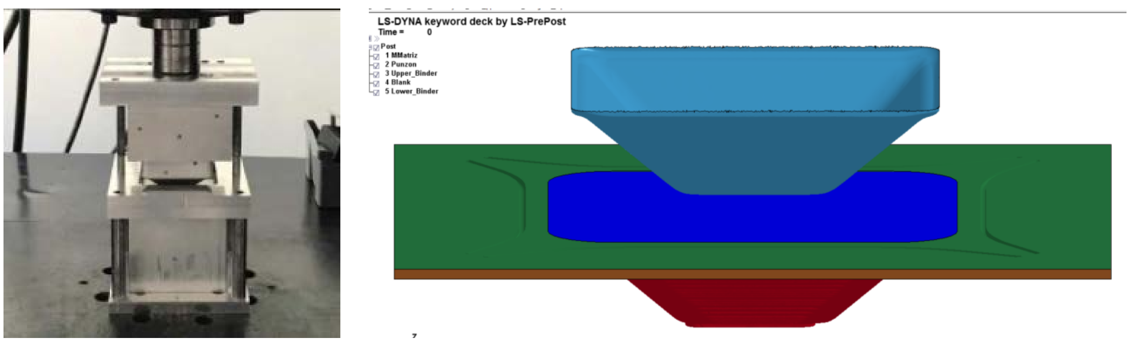

Figure 4. (Left) Stamping dies mounted in the Universtal Testing Maching, (right) Stamping model at initial position.

Results

ISF Simulation

The computational time of the ISF analysis was 8.5 hours. Springback simulation was conducted after the forming stage and the resulting mesh exported in STL format for comparison with a digitized model of the fabricated part using the GOM Inspect software.

Figure 5 shows the deviations, in millimetres, between simulation and physical part geometries. As can be observed, accurate predictions (<1 mm) can be obtained at the walls of the pyramid. However, the model fails to predict the bottom of the pyramid shape, what in the literature is called the pillow effect.

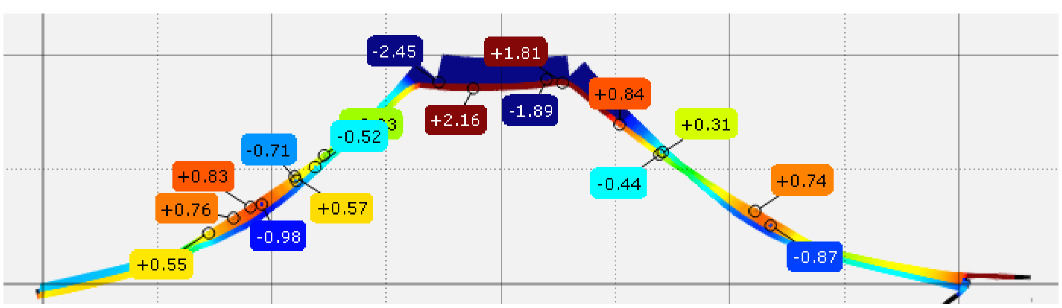

Figure 5. Geometric deviation, in mm, between the physical and virtual parts.

Figure 6 shows a comparison of the physical/virtual parts' thicknesses. The fabricated component measurements indicate a minimum thickness of 0.37 mm at the wall while the lowest simulation shell thickness prediction is 0.33 mm.

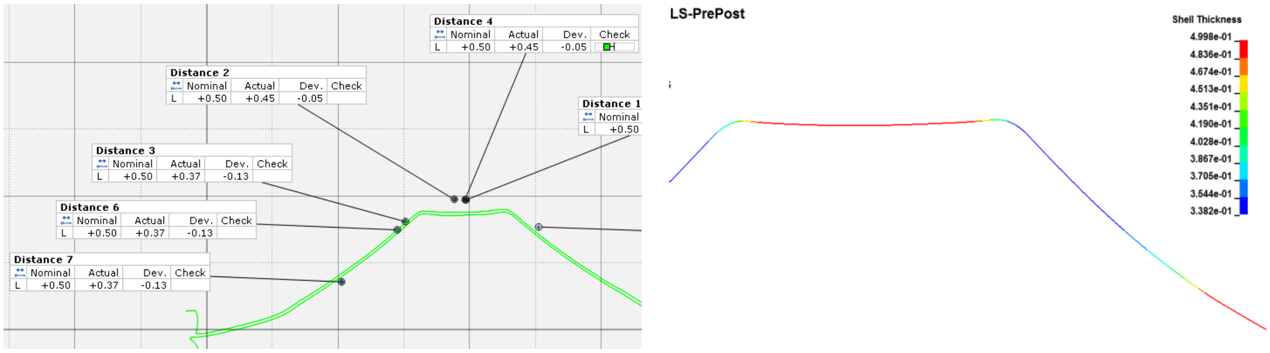

Figure 6. (Left) Thickness measurements on one fabricated part. (Right) Model shell thickness.

Stamping Simulation

The elapsed solution time was 3 hours. As shown in Figure 1 (right), the fabricated part had wrinkles in the sides, which were predicted by the simulation. This defect led to a binder redesign in order to include drawbeads which limited the flow of the material. Figure 7 compares the predicted formability for the components with and without drawbeads. Finally, Figure 8 shows the physical plate with drawbeads and one of the obtained stamped parts.

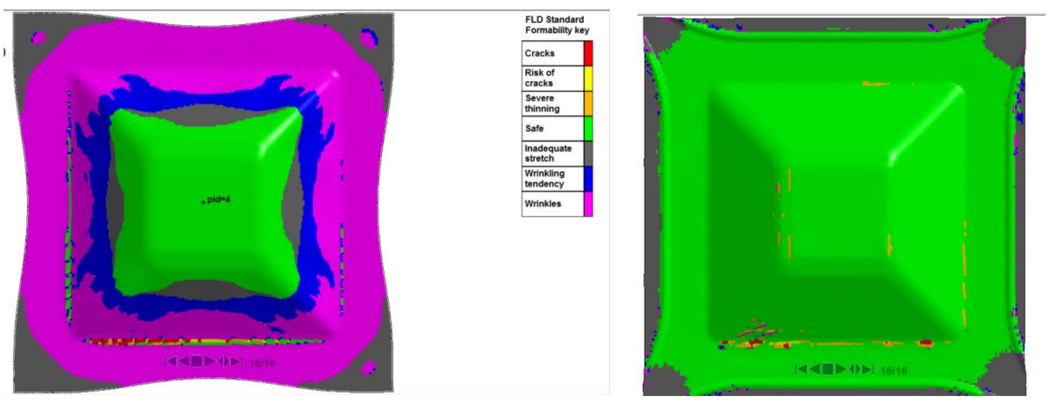

Figure 7. Formability of the Stamped component without (left) and with (right) drawbeads.

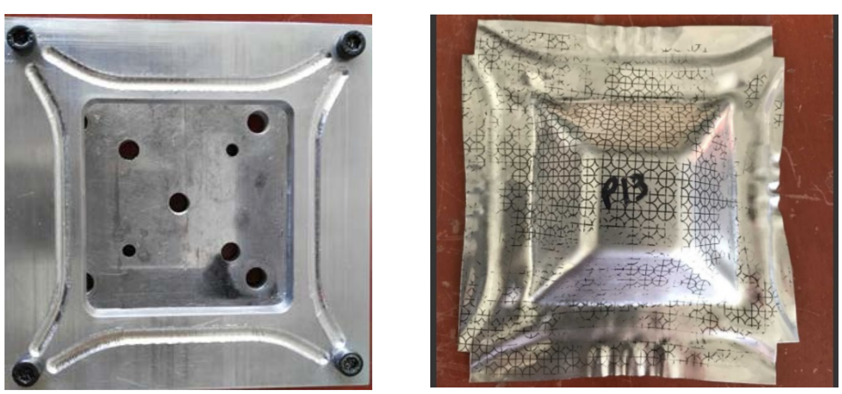

Figure 8. (Left) Binder with drawbead and (right) the resultant component without wrinkles.

Discussion and future work

As shown in the previous sections, the followed methodology was accurate enough to predict final shape and thickness of the components. Although not shown, the stamping simulation predicts 0.4 mm at the pyramid walls which is consistent with the grid deformation analysis conducted in the part.

Further efforts will be oriented to the: (i) Scanning and comparison of CAD design, FEA results and physical components, for both processes, (ii) implementation of properties obtained from tensile tests of the actual material, (iii) validation of numerical strains using analytical models and (iv) comparison of experimental and numerical stamping forming force.

Regarding ISF, at least two improvement alternatives will be explored: a) using a 3D printed die underneath the blank, or b) modify the tool-path in those places with higher geometry deviations.

In the case of Stamping, simulations gave invaluable information that led to redesign the process, which finally meant a safe component.

References

[1] Feng R. et al, 2010. Process Modeling of Freeform Incremental Forming Using LS-DYNA. Proceedings of the 11th Int'l LS-DYNA Users Conference.

[2] Taleb-Araghi, B. et al., 2009. CIRP Annals - Manufacturing Technology Investigation into a new hybrid forming process : Incremental sheet forming combined with stretch forming. CIRP Annals - Manufacturing Technology, 58, pp. 225-228.