Developments in Line-Die Simulation and Exterior Surface Quality Check

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Abstract

A review of recent developments in stamping manufacturing will be conducted. The review will be focused in area surrounding the new line die simulation capabilities and in exterior surface panel quality check.

Line Die Simulation

Over the past year, under close collaboration with the world's leading engineers and top researchers of automotive OEMs, LS-DYNA® has undergone significant improvements in stamping simulation. Some of the most important features and their applications will be reviewed.

Line die simulation has been conducted in LS-DYNA since 2000. It has been for a long time that the next die process simulation has to wait until the current process simulation completes, or travel the tools unnecessary distances wasting CPU time to make the entire process continuous. In trimming, one has to wait until the draw process completes in order to specify a seed node to identify which portion of the panel to be trimmed away or to be kept. Although in some instances where trim curves are simple then a parent node can be used for locating the seed node, the existing capability is not sufficient for a robust and continuous process simulation. In a major push by one of the leading OEMs, capabilities related to line die simulation have been completely revamped.

To eliminate the unnecessary tool travel between the die process stages, tools and blanks (or drawn, or trimmed panels) are now automatically positioned using keyword *CONTROL_FORMING_AUTOPOSITION_PARAMETER_SET [1], short for *CFAPS. This feature enables users to define, ahead of time, sets of slave and master part, and within each set how the slave is to be positioned relative to master. With all tools initially positioned at home (leave appropriate gap for stop block application) by the user, LS-DYNA will automatically calculate the optimal distance between each pair of slave and master part and position them accordingly in the beginning of the simulation, using keyword *PART_MOVE. Part set IDs are now accepted in this keyword. Tailor-welded blanks are accounted for in this new feature by simply using the option _SET, and include both thin and thick side of the blanks in the same part set ID. In fact, this new feature can be used throughout the process simulation to automatically position the tools and blank. In case where punch support is needed and where binder travel is dictated by process intent, a distance is entered in PREMOVE under *CFAPS. The calculated moved distances for all parts, or part sets are stored in variables, defined with keyword *PARAMETER. These calculated variables can be used to further calculate the detailed simulation time, for example, closing and drawing time, given the tool speeds, which could also be assigned as variables. These calculations within the LS-DYNA input file are done with keyword *PARAMETER_EXPRESSION. Standard FORTRAN expressions apply. In addition, all time related entries can be expressed in this way. The entries include, but not limited to, those in keywords *CONTROL_ADAPTIVE, *BOUNDARY_ PRESCRIBED_MOTIION_ RIGID, *DATABASE, *DATABASE_BINARY_D3PLOT, and load curves in *DEFINE_ CURVE used to describe tool kinematics. A more straightforward presentation is shown in Figure 1. The input sequence for the auto position and calculation portion of the input deck needs to follow the flow as shown in Figure 2.

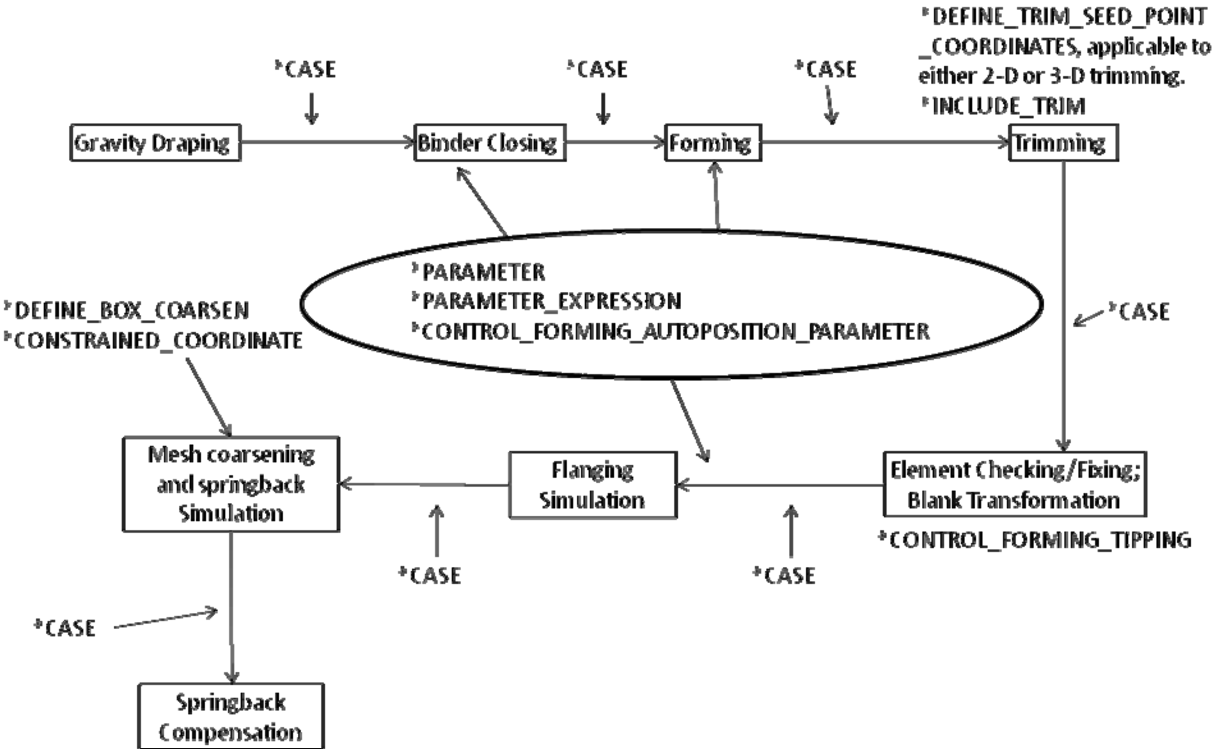

Figure 1. A Fully Automatic Line Die Simulation Process

Seed node for trimming application can now be defined with position coordinates, as opposed to nodal ID. Typically a node from the stationary post (which has the same position as a drawn panel) is selected, and its coordinates are used in the new keyword *DEFINE_TRIM_SEED_POINT_COORDINATES [2]. This new feature applies to both 2-D trimming routine, as defined by *DEFINE_CURVE_TRIM_NEW, and to 3-D trimming routine, as in *DEFINE_CURVE_TRIM_3D. Note that in the 3-D trimming routine, one trim curve is allowed to form one complete loop, so concatenate the trim curves for 3-D trimming application. In addition, an improved trimming function, activated with a new option *INCLUDE_TRIM to include the dynain file of the drawn panel, delivers with considerably less memory (over 50% reduction) and CPU time when compared with the original *INCLUDE, as shown in Table 1. This reduces the per core memory requirement when working on the trimming in MPP environment.

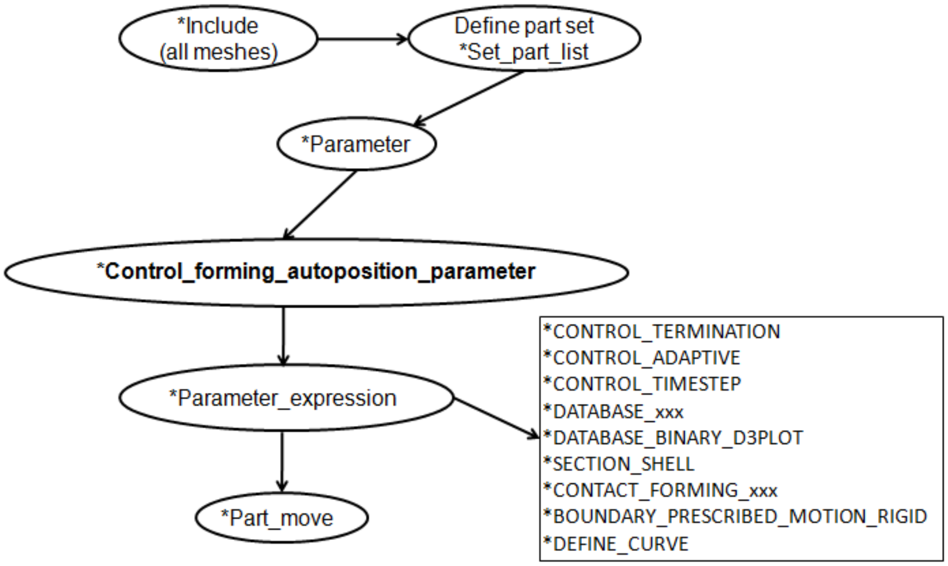

Figure 2. Parameterized Auto Position and Auto Calculation

It is often necessary to re-tip the part between the line dies. A new keyword, *CONTROL_FORMING_TIPPING [3] is especially developed for this purpose. Working well with the keyword *CASE, which is used to link all simulation processes together, the keyword handles multiple translations and rotations of the part and its strain and stress tensors. Keyword *CASE also allows for switching of LS-DYNA executables (for example, single or double precision) between the die processes.

*Table 1. New keyword *INCLUDE_TRIM trims away the CPU time and memory requirements.*

	Roof	**Hood Inr**	**A/SP B-Plr**	**NUMISHEET Fender**	**BSA Otr**	**Door Otr**	**Wheel house (2 in 1)**	**Boxside Otr**
# Element	410810	1021171	351007	189936	380988	315556	261702	1908369
CPU (old/new)	7m26s/ 4m	10m20s/ 9m18s	3m11s/ 2m56s	2m6s/ 1m22s	5m45s/ 4m54s	4m27s/ 3m35s	2m52s/ 2m30s	27m31s/ 13m59s
Memory (Mwords) (old/new)	282/ 112	616/ 383	221/ 117	119/ 50	233/ 130	217/ 114	157/ 75	1150/ 539

Constraints in springback were imposed on the nodal IDs. A new keyword *CONSTRAINED_COORDINATE [4] enables multiple constraints to be applied based on position coordinates.

Now the constrained locations can be exactly as the same as specified in the GD&T data, and can be defined ahead of time.

Based on different die processes, templates can be set up for specific purpose and reused for future simulation. All these new improvements in the line die simulation allow for a stamping process to be defined in the beginning of the simulation and continuously run to completion without interruption.

Exterior Surface Quality Check

The prediction of surface distortion [5], often called ‘mouse’ or ‘teddy bear’ ears existing in exterior surface panels, has drawn much interest over the years. Visible only to trained eyes of experienced stamping engineers, the surface distortions are often very minute (typically in the order of 1.0E-2 mm), requiring extraordinarily high accuracy in forming and springback simulation. Coupled with the latest technologies in LS-DYNA, such as static implicit binder closing, flanging simulation and surface smoothing, a new stoning feature is now available to predictively identify and quantify the stamping defect. This also means the accuracy of LS-DYNA in stamping simulation has reached a new height.

Stoning calculation in LS-DYNA is activated via a new keyword *CONTROL_FORMING_STONING [6]. A successful stoning simulation requires accurate simulation process and results for the entire die processes. For example, a typical process includes gravity, closing, forming, trimming, flanging and springback.

Exterior class-A surfaces are typically large and un-supported during closing, causing much inertia effects and extra artificial length of line within punch opening if dynamic explicit method is used. This effect influences the prediction of surface distortion. Static implicit method is recommended for binder closing, with *CONTROL_IMPLICIT_FORMING option 2.

Starting with an original mesh size of 12 mm, blank mesh can be refined locally only in the areas of interest, to the tone of 1.5mm, as shown in Figure 3. A coarser mesh can be refined quite easily using LS-PrePost/Page2/ELEDIT/Split. With this ‘Split’ feature, boundary nodes between coarser mesh and finer mesh are automatically constrained with *CONSTRAINED_ADAPTIVITY. No mesh adaptivity should be employed in the finer mesh areas. Typically no mesh adaptivity is needed during the static implicit binder closing. A limited adaptive level 3, reducing the element size to 3.0mm, can be activated in explicit dynamic drawing only for those areas which are not of concern, by setting ADPSIZE to 4.0mm. Blank is modeled with fully integrated shell type 16 with through thickness integration points of 7. Mass scaling needs to be limited to a smaller number, in the rage of -7.0E-07 to control the local inertia effects. Springback should be simulated without mesh coarsening feature.

To accurately capture the intended surface curvature, ‘SMOOTH’ option [7, 8] in *CONTACT_FORMING_SURFACE_TO_SURFACE_SMOOTH is recommended to be used locally, in the same areas of interest. In SMOOTH contact regions, tool mesh sizes need to be limited to no more than 25mm, with chord deviation of 0.03 and minimum size of 0.03.

Stone length and width can be set typically to 150.0 and 40.0 mm, respectively. The step size of the moving stone is set to the similar order of magnitude of the smallest element length. A feature called 'DIRECT' allows the automatic definition of the stoning directions. Any number of directions can be defined but typically '2' is used. The CPU time required for the stoning calculation is trivial. Since stoning is performed on the outward normal side of the formed mesh, element normals need to be oriented accordingly and consistently. Alternatively, 'REVERSE' feature provides an easy way to reverse the element normals in the beginning of the computation. Stoning direction is defined by two nodes, NODE1 and NODE2. Alternatively, NODE1 and NODE2 can be left blank and the stoning directions will be automatically determined by using 'DIRECT'. A large area of mesh can be included during stoning. An ELSET must also be included, which can be used to define a local area that requires stoning computation. Alternatively, an ELSET can define several local areas to be used for the computation. Furthermore, an ELSET should not include meshes that have reversed curvatures. An ELSET can be easily generated using LS-PrePost, in page 5, under SetD. The stoning simulation results is output in a file named "stoning.output". The stoning results can be viewed using LS-PrePost, in page 1, under FCOMP/Thick/ Shell_Thickness.

An example of a stoning analysis on a Ford Econoline door outer panel is provided below for reference. The die surface is developed using the original crash simulation mesh from the website of National Crash Analysis Center at The George Washington University. The geometry in the door handle area was heavily modified for an enhanced stoning experience, Figure 4. In Figures 5 and 6, draw, trimming and springback results are shown. In Figure 7, stoning simulation was performed for the upper and lower left corners of the door handle, represented by two element sets as marked. Surface lows are predicted at the two corners as shown in the color contour.

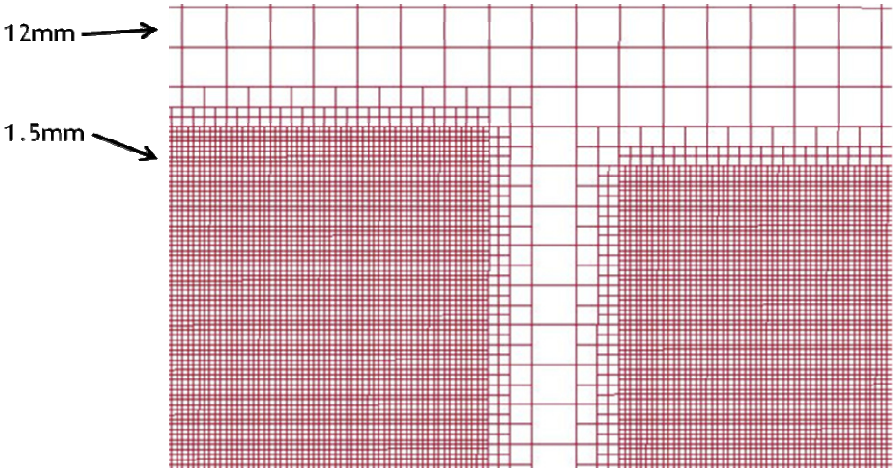

Figure 3. Blank Mesh Size for Stoning

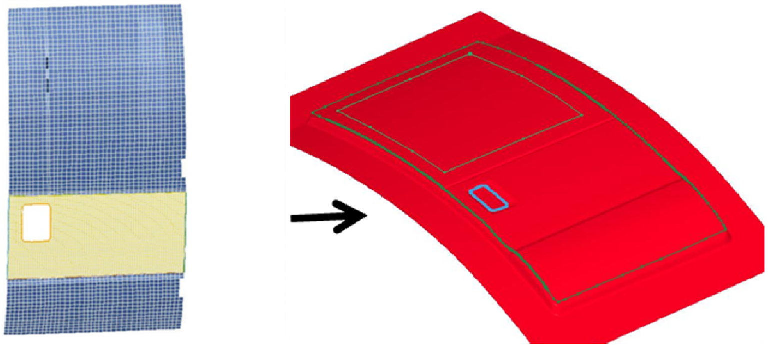

Figure 4. Original NCAC Door Outer Model and Die Face

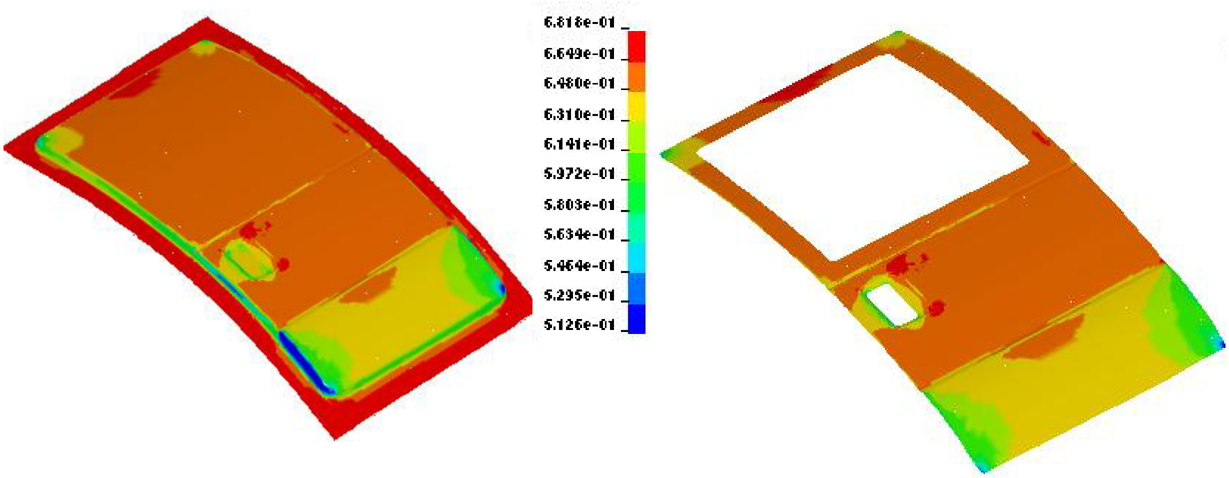

Figure 5. Shell Thickness (mm) Contour After Draw and After Trimming

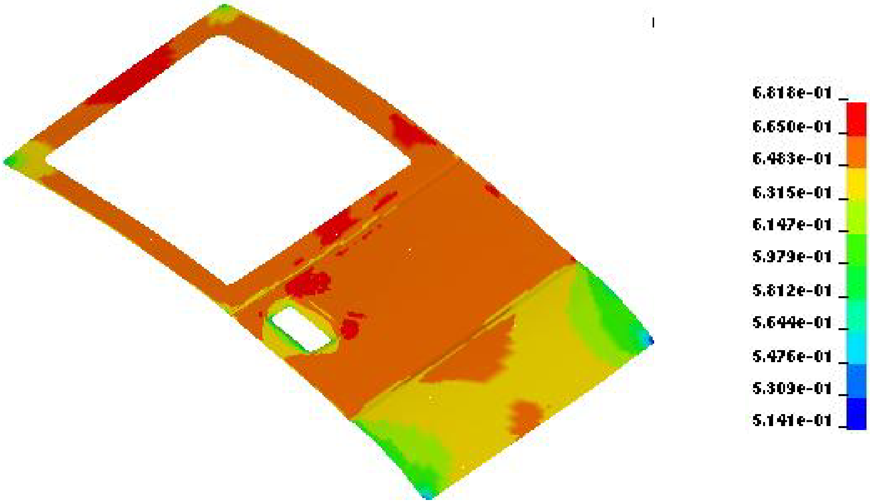

Figure 6. Springback Amount in Z (mm) After Springback Simulation

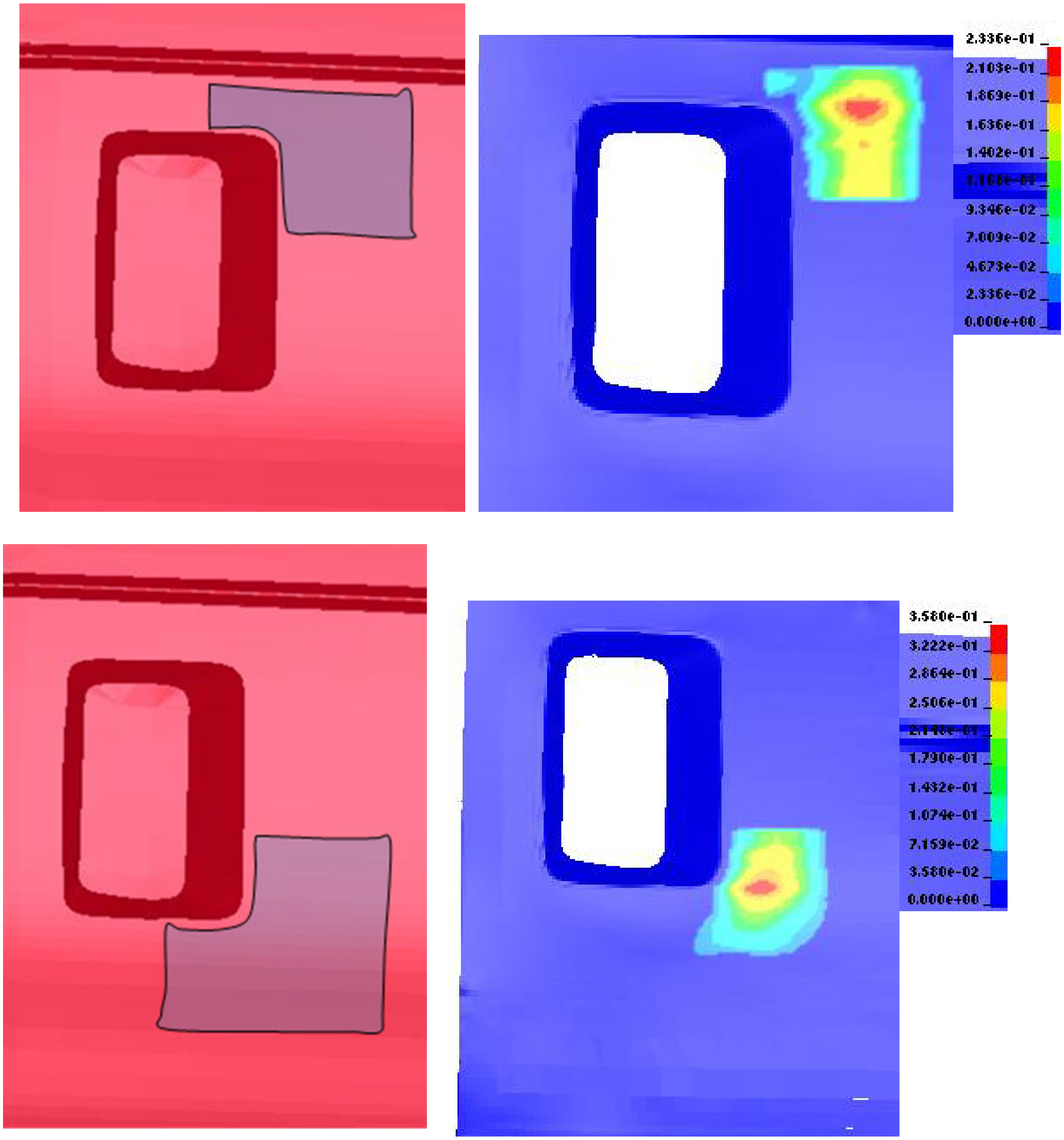

Figure 7. Element Sets Selected (left) and Stoning Results (mm) (right)

Conclusion

Developments in LS-DYNA have been traditionally customer-focused and it has contributed critically to the advancements of the software and to our continued success. And this tradition has further strengthened LS-DYNA's premier position in stamping and manufacturing engineering. We are grateful to be able to work with the industry's best as the stamping and manufacturing industry meets its next challenges.

Acknowledgement

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References

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