Advancements in Material Modeling and Implicit Method for Metal Stamping Applications

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Abstract

A review of recent developments in stamping manufacturing will be conducted. The review will be focused on discussions surrounding new features related to static implicit binder wrap, advanced material modeling with Yoshida's non-linear kinematic hardening in conjunction with Hill's 1948, Barlat 1989 and Barlat 2000 yield criteria.

Introduction

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

Static Implicit Application

Compared with dynamic explicit simulation, static implicit results are insensitive to tool speeds and mass scaling, thus minimizing inertia effects. It also comes with larger time step size, which is independent of minimum element characteristic length. Optimized within the implicit routine, memory usage is now very reasonable for production intent application. Although it comes with somewhat more CPU time for large model results are most accurate and consistent. It is now very robust, reliable and most ideal for large, flexible and unsupported stamping applications, such as binder closing, pad closing (clamping) in line-die simulation, redraw and free flanging.

The presence of inertia effect in an otherwise static metal forming process can affect the accuracy of the simulation, for example, in panel breakdowns, springback, and clamping phase of a flanging simulation. The effect is particularly significant in large and flexible exterior panels. This negative effect can be mitigated by slowing down tool speed and using very little or no mass scaling. Still, presence of 'waves' can be seen through the animation, and computing time could be long. Now the implicit static binder wrap feature, which represents a major development two years in the making, is available to completely eliminate the undesirable effects. Computation times typically range from 10 to 20 minutes for a coarse mesh size of 25x25mm. It works well with adaptive re-meshing and 'non-sticky' option (set IGAP=2 in *COTACT), which often prevails in the sheet metal forming situation. Comparisons between dynamic and static binder closing of exterior panels are striking. In place of the wavy blank from the dynamic effect is the smooth wrapped blank showing just the buckles (if exist), and nothing else artificial. This powerful feature is activated using keyword *CONTROL_ IMPLICIT_FORMING, type 2. This implicit static feature has been applied in daily production simulation for more than 1 year and feedbacks from the users have been very positive. Figure 1 shows a series of binder closing breakdowns on a NUMISHEET'05 decklid inner. The same method, when applied in the clamping phase of a flanging simulation, eliminates any of the dynamic effects caused by explicit dynamic method. Shown in Figures 2 and 3 are the clamping breakdowns of a section on a NUMISHEET'02 fender outer panel. Furthermore, it is also now feasible to conduct gravity loading and binder wrap in a single step using implicit static method. In addition, the implicit static method is also being developed, tested and employed in a wide range of problems in flanging process simulation and initial feedbacks and results are encouraging. Finally, the same feature, when applied in springback simulation, speeds up the CPU time by a factor of more than two.

An example of the method applied in a complex draw and multi-flanging process is shown in Figure 4. A portion of the flange, which is under a free flanging condition, is shown after the last flanging action. Severe wrinkles are present because of the shrink flanging condition.

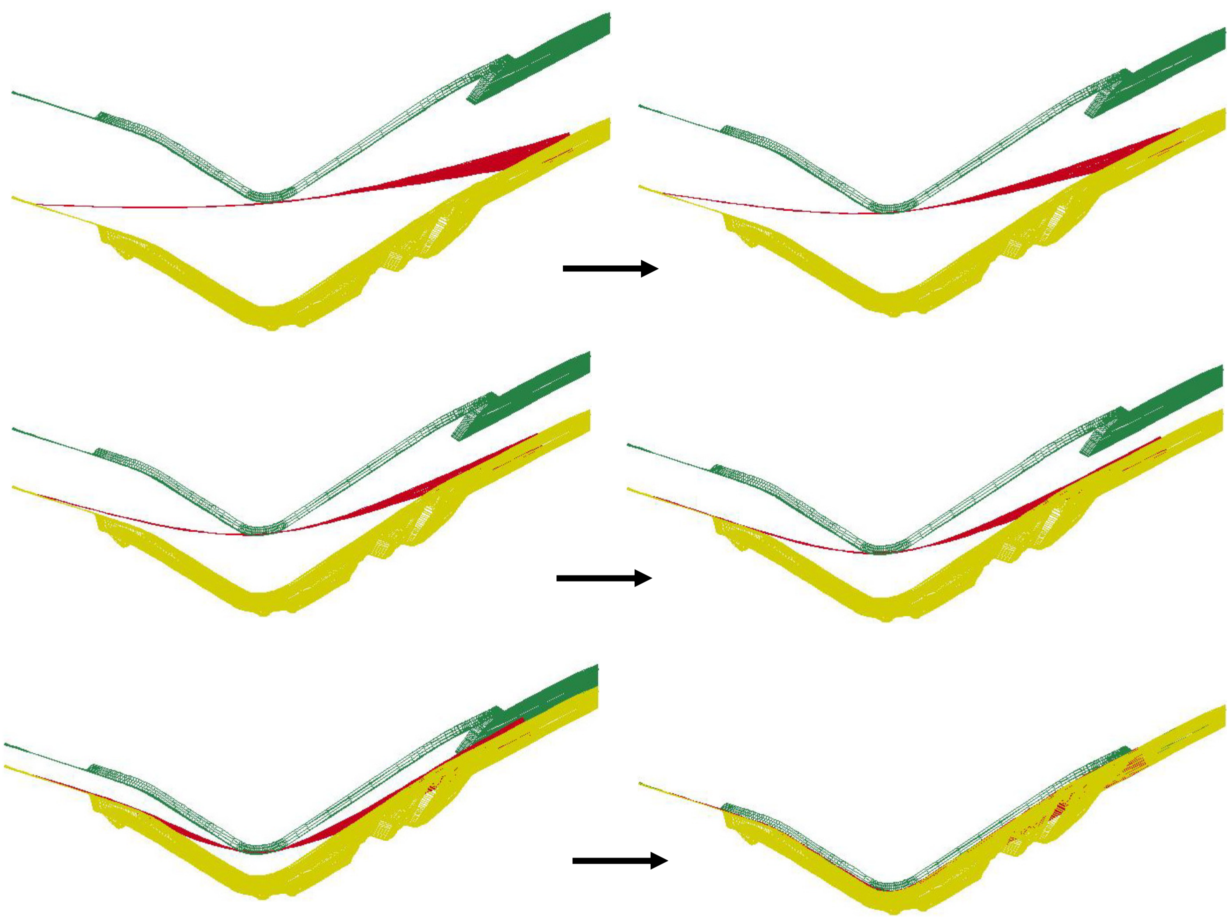


Figure 1. Binder Wrap of NUMISHEET'05 Decklid Inner with Implicit Static Method with Adaptive Re-meshing

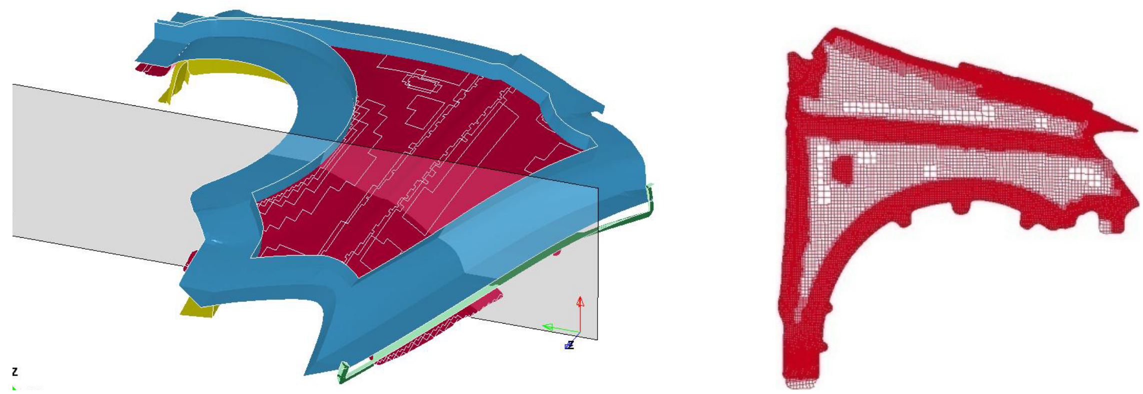
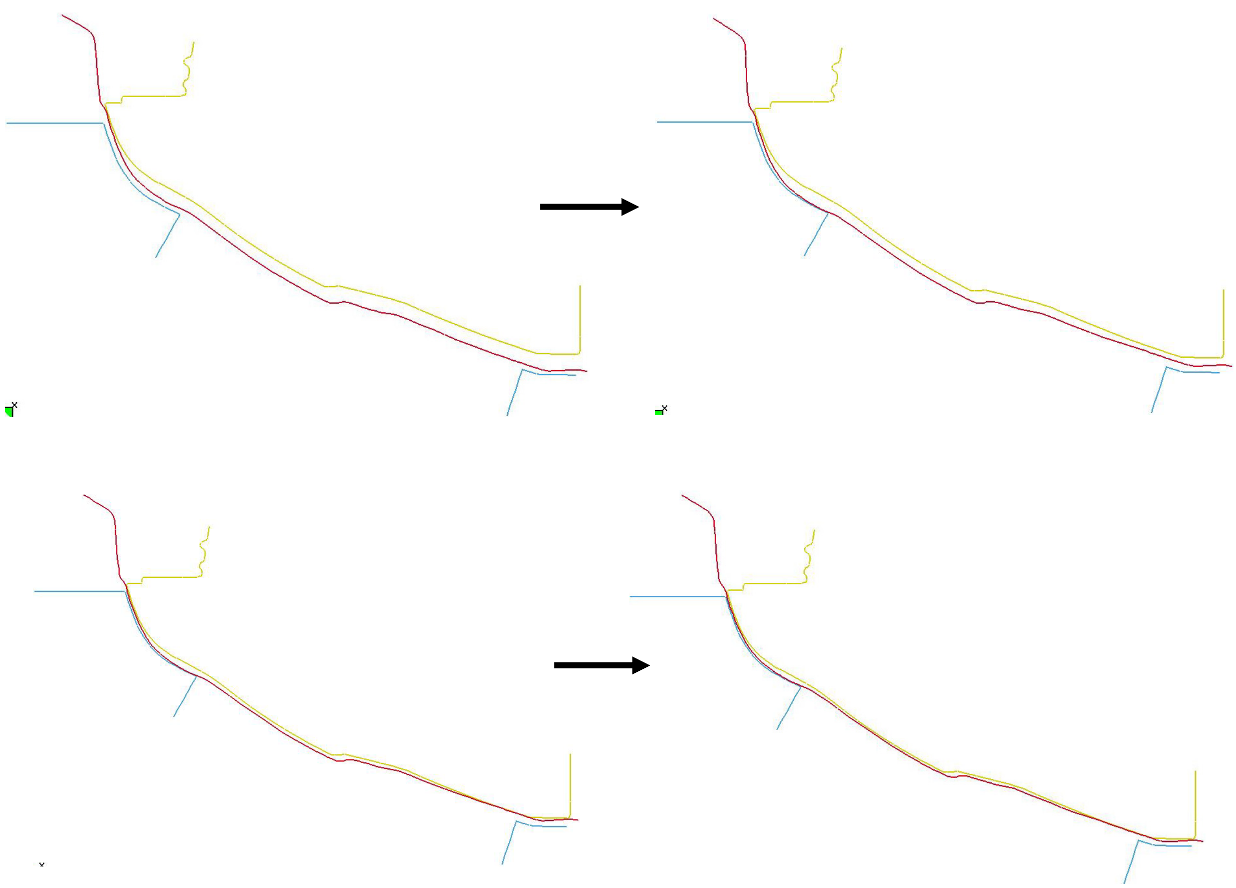


Figure 2. NUMISHEET'02 Fender Outer Section Cut Location and Trimmed Blank



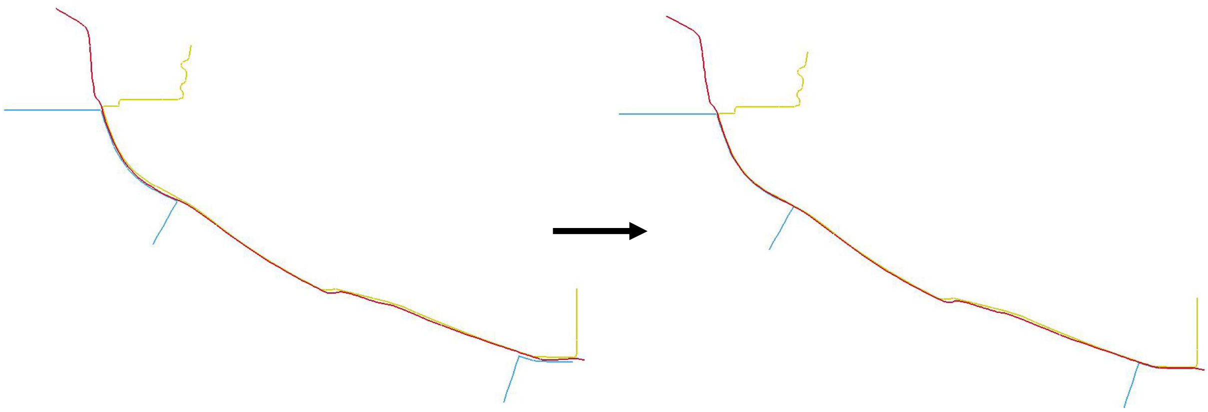


Figure 3. Clamping of NUMISHEET'02 Fender Outer with Static Implicit Method in Flanging Simulation

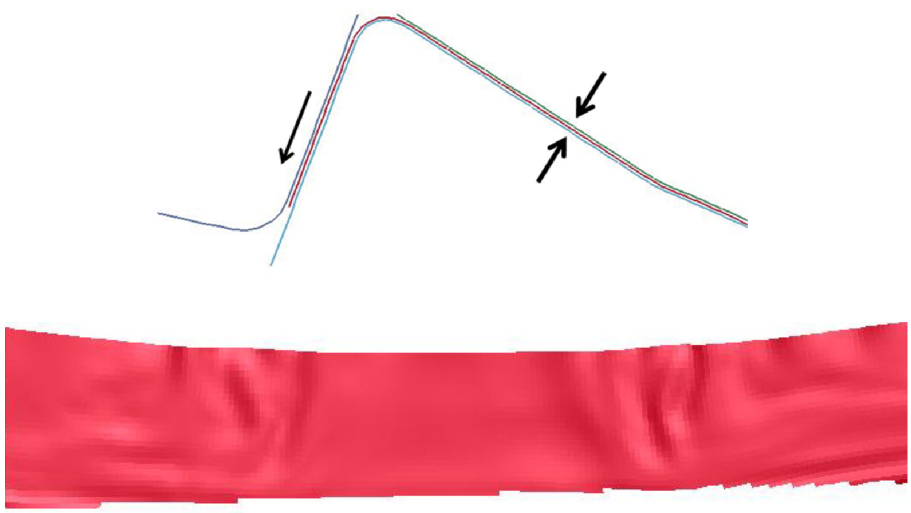


Figure 4. A Portion of a Flange After Flanging Process Simulation

Advance Material Models

Significant progresses have also been made in springback prediction of Advanced, Ultra High Strength Steels (AHSS and UHSS), and Aluminum. One of the problems in AHSS and UHSS was that twisting mode could not be reliably predicted for rail-type of deep drawing parts. With the implementation of Yoshida's non-linear kinematic hardening [1] model (*MAT_125), coupled with Hill's 1948 yield criterion, the prediction accuracy has been improved dramatically. The Yoshida's model accounts for cyclic plasticity including Bauschinger effect and cyclic hardening behavior, and has been found more suitable for application with AHSS/UHSS. Yoshida's theory describes the hardening rule with 'two-surfaces' method: the yield surface and the bounding surface. In the forming process, the yield surface does not change in size, but its center moves with deformation; the bounding surface changes both in size and location. The further improvements in the original Yoshida's model implemented in LS-DYNA included modifications to allow working hardening in large strain deformation region [2]. The modified material model now entails a total of 9 parameters to describe the effect. Detailed discussions and results on the work can be found in the reference. More recently, the modified Yoshida's non-linear kinematic hardening model was further developed with the 3-parameter material model of Barlat and Lian's 1989 yield criterion (*MAT_KINEMATIC_HARDENING_BARLAT89, or, *MAT_226) [3], which is more suitable for Aluminum metal sheets under cyclic plasticity loading, and with anisotropy in plane stress condition. Lankford parameters R_0, R_{45} and R_{90} in rolling 45°, and 90° directions, respectively, are used for the definition of the anisotropy. Material parameter inputs are fairly straightforward, and it's a combination of parameters needed for *MAT_125 and *MAT_036. Fully developed, calibrated and rigorously tested on both SMP and MPP platform, this latest material model has shown excellent results on a single element in uni-axial stress, plane strain, equal bi-axial, and simple shear tests, and among some nine production-intent stamping dies of all possible die simulation processes. Full benchmark test on the NUMISHEET 2005 cross member, with Aluminum alloy AL5182, has shown the full potential of *MAT_226 in capturing the true springback behaviors of the Aluminum sheet. In Table 1, the 9 parameters required for the modified Yoshida's hardening model is listed. In Figure 5, simulation specification for the benchmark is shown. Figure 6 & 7 illustrate the springback simulation results at section Y=0.0, and Y=-370, respectively. While Figure 6 shows all three material models all comes very close to the measured data, Figure 7 shows *MAT_226 results are remarkably closer to the experiments than those of *MAT_037 and *MAT_125.

*Table 1. Material Parameters for *MAT_226 for Aluminum 5182 Application (NUMISHEET'05).*

	CB	**SIGY**	**C**	**K**	**Rsat**	**SB**	**H**	**C1**	**C2**
AL5182 (NUMI-SHEET'05)	162.0	128.0	451.0	10.0	171.0	243.0	0.19	0.01	0.32
	R_0	**R_{45}**	**R_{90}**						
	0.957	0.934	1.058						

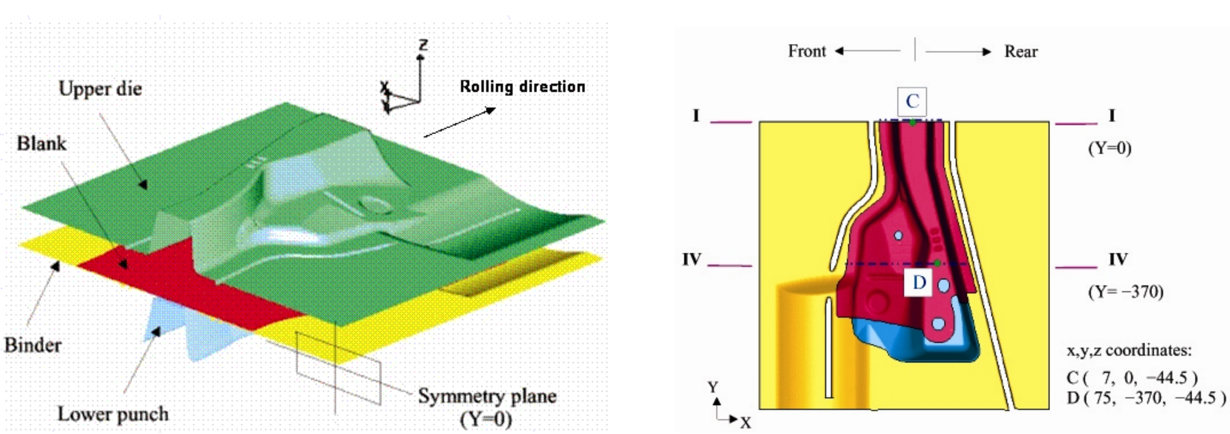


Figure 5. NUMISHEET'05 Cross Member and Section Cut Location

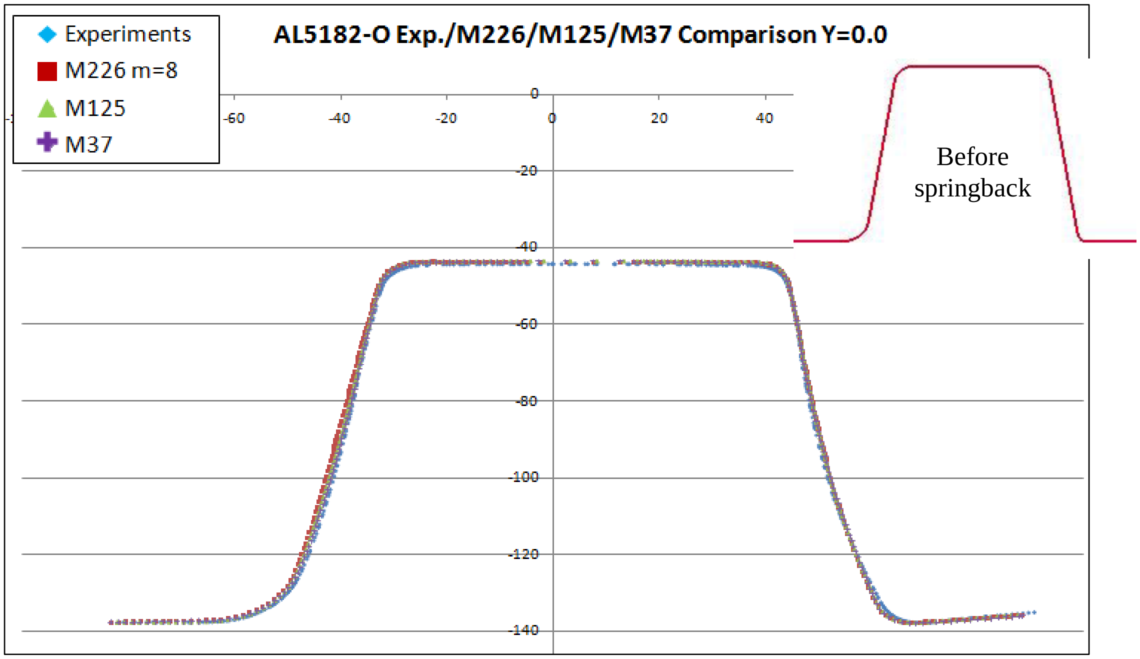


*Figure 6. Comparison of springback among *MAT_037, *MAT_125 and *MAT_226 at Y=0.0*

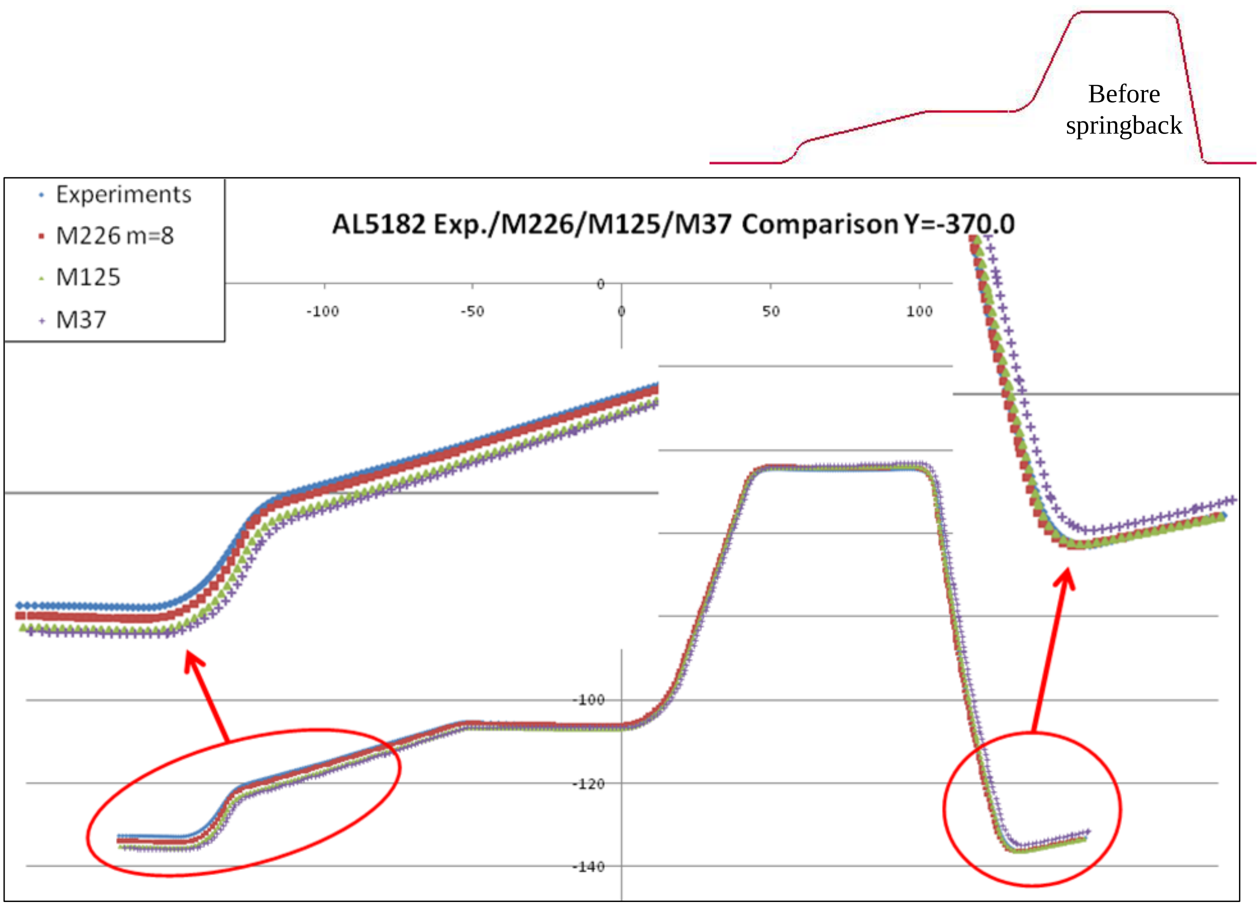


*Figure 7. Springback Comparison *MAT_037/*MAT_125/*MAT_226/Measured at Y=-370*

Even more recently, *MAT_KINEMATIC_HARDENING_BARLAT2000 (*MAT_242) was developed to couple the modified Yoshida's hardening with BARLAT's 2000 yield criterion. Barlat's 2000 yield criterion is described with 8 parameters as listed in Table 2 for the cross member. The same hardening parameters listed in Table 1 was used for the modified Yoshida model. Preliminary results show the model has captured springback at section Y=0.0 very well, Figure 8. A maximum 5mm deviation from the measured data is shown in Figure 9 for the section at Y=-370. Further improvements are being made for better results.

*Table 2. Material Parameters for *MAT_242 for Aluminum 5182 Application (NUMISHEET'05).*

AL5182 (NUMI-SHEET'05)	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	
	0.9360330	128.0	451.0	10.0	171.0	243.0	0.19	0.01	

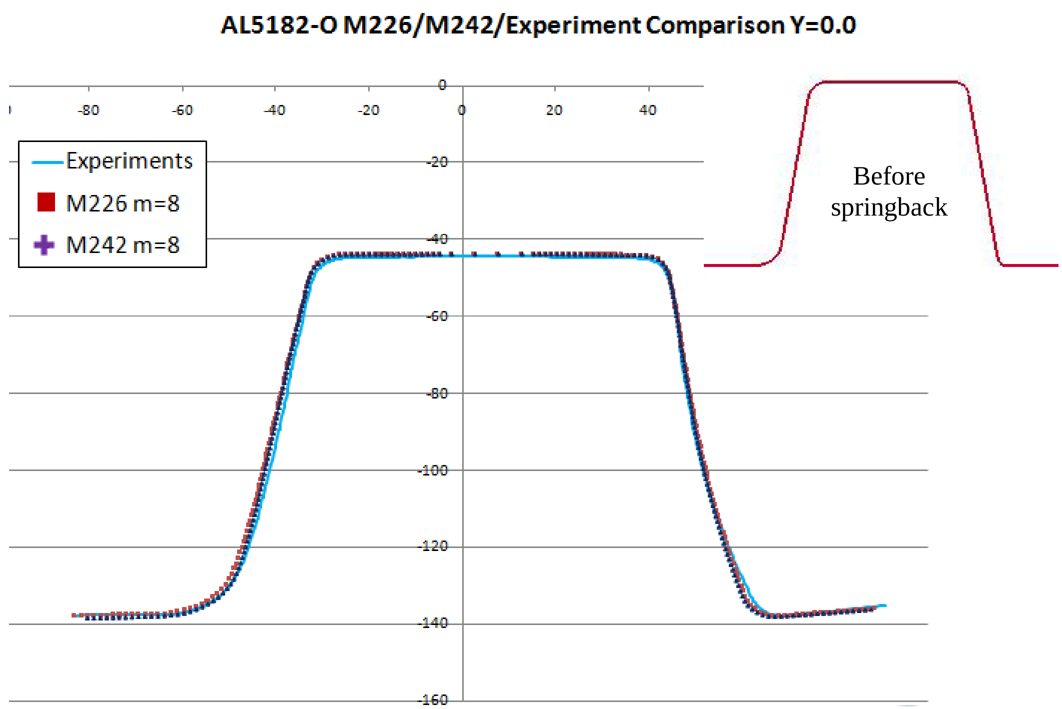


*Figure 8. Comparison of springback between *MAT_226 and *MAT_242 at Y=0.0*

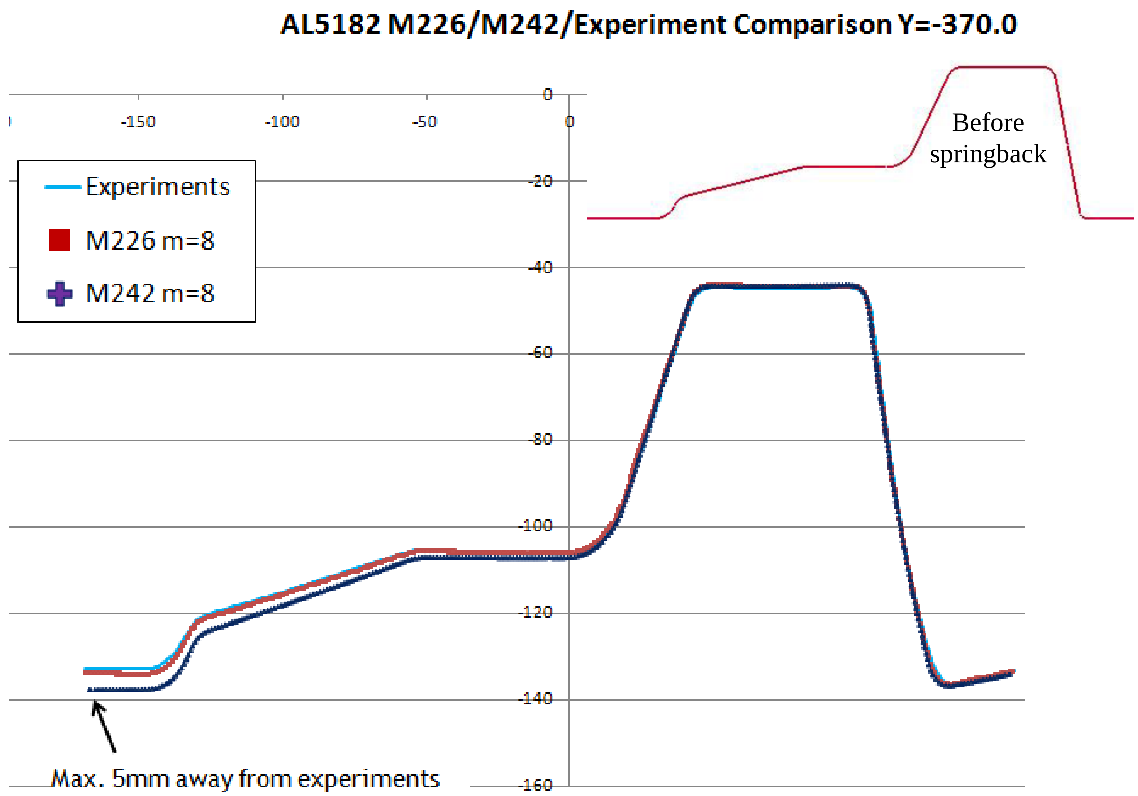


*Figure 9. Comparison of springback between *MAT_226 and *MAT_242 at Y=-370.0*

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.

Acknowledgment

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References

1. F. Yoshida, T. Uemori, "A model of large-strain cyclic plasticity describing the Baushinger effect and work hardening stagnation", *Int. J. of Plasticity, vol.* ***18****, 661-689, 2002.*

2. M. F. Shi, X. Zhu, C. Xia, T. B. Stoughton, "Determination of nonlinear isotropic/kinematic hardening constitutive parameters for AHSS using tension and compression tests", *NUMISHEET 2008, pp.137-142.*

3. LSTC Metal Forming Application Manual pages - *MAT_226.