Springback Simulation of the Numisheet 2005 Benchmark II Using DP600

(The Effect Of Using 21 Through Thickness Integration Points and Using a Static Implicit Finish to the Forming Simulation)

Tim Lim and Tim Dietrich
Dofasco Inc
Hamilton, Ontario, Canada

Abstract

This study uses a design of experiments (DOE) methodology to investigate the sensitivity of springback prediction to various numerical parameter for the Numisheet 2005 cross member (Benchmark II). The parameters investigated are; through thickness integration points (21 Gaussian integration points through the thickness vs. 7), using a static implicit finish in the forming simulation, element size (number of adaptive levels), and coulomb friction. The average effect of these parameters on the resulting springback was then quantified. Overall, it was found that element size and friction have the greatest effect on the predicted springback and that little is gained by using an implicit finish and 21 integration points through the thickness. Possible reasons for this are discussed and it is then stressed that, these results cannot be generally applied to all situations. In other words, the results point to the possibility that some parts (such as this one) are not sensitive to increasing integration points (from 7 to 21) or an implicit finish. It was also found that despite all combinations of numerical parameters, the wall curl on one side of section I of the Benchmark could not be reproduced.

Introduction

Springback prediction using the “explicit forming/implicit springback method” produces results that typically under predict actual springback (for an isotropic hardening material). One contributing factor (among others) is that forming stresses are not accurately predicted at the end of the punch stroke. Two important factors that affect the predicted stress distribution are: the number of through thickness integration points used, and minimizing artificial dynamics at the end of the forming stroke. Wagoner et al.[1] has shown that predicted springback magnitudes for the draw bend test, oscillate and then converge to a stable solution with Gaussian 51 integration points; however, in practical terms, 21 integration should be sufficient producing approximately 1% error. Other workers have also highlighted the importance of minimizing artificial dynamics and modeling practices have been recommended for this purpose [2].

The objective of this work is to specifically investigate the impact on springback prediction (for the 2005 Numisheet Benchmark II part) using 21 integration points through the thickness and an implicit finish to the forming simulation. In theory, this should provide a more accurate prediction of the forming stresses at the end of the punch stroke. Other common numerical parameters are investigated such as friction and element size. All parameter effects on the predicted springback displacements were then compared.

Baseline Forming and Springback Models

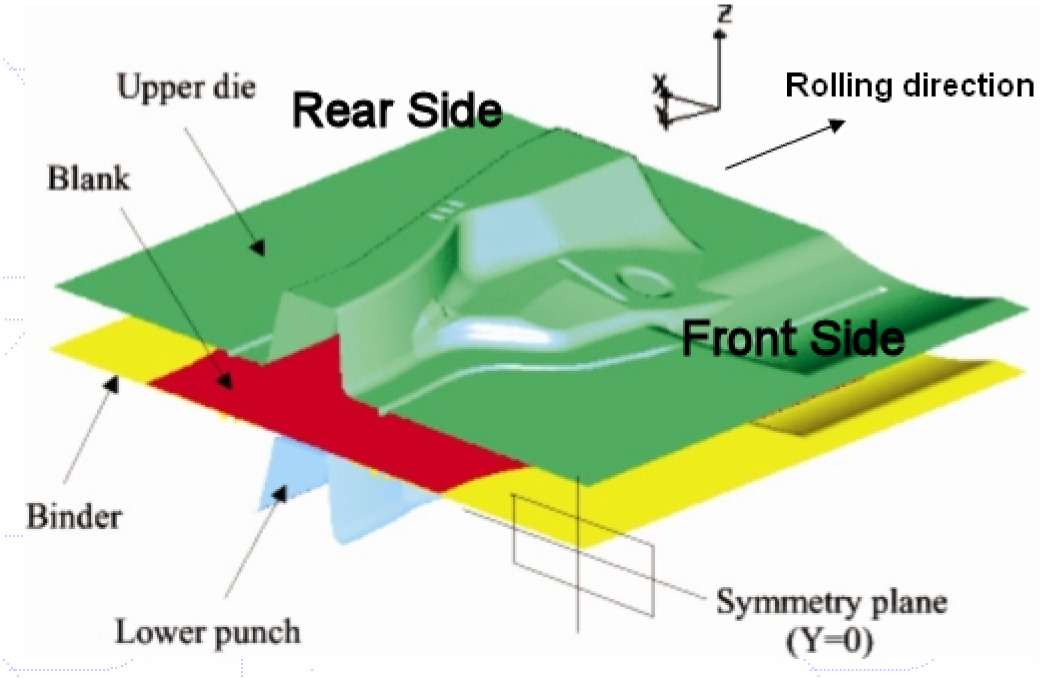

Figure 1: Numisheet 2005 Benchmark II.

The Numisheet Benchmark II model is an automotive underbody cross member in which bending / unbending deformation dominates forming, and springback [3]. The base forming/springback model was constructed using the forming conditions outlined in the benchmark and the specific parameters outlined below [4-6].

- Trapezoidal upper die velocity profile (Maximum velocity of 2 m / sec, .02 seconds for ramp up and ramp down),
- One way forming contact on all tools using a penalty factor of 0.1,
- Shell element formulation #16 for both forming and springback,
- 750 cycles per mm of punch travel
- Material model "Mat 37, Transversely_Anisotropic_Elastic_Plastic",
- Look forward adaptively (same adaptive frequency for all simulations),
- Starting element size of 10x10 mm
- Rigid body stoppers used on binder (maximum velocity of 2 m/sec, maximum positive displacement of 0.01 mm).
- Implicit springback simulation with 4 springback steps

From animations of preliminary simulations, it was observed that the blank material that passes through the draw beads at the section of the part near the symmetry plane (Figure 1), also eventually reach the wall of the part. This was also observed for the rear side draw bead at the opposite end of the part (away from the symmetry plane). In these areas the bending/unbending deformation in the draw bead should contribute to springback (curl) in the wall. For this reason, physical draw beads were used for all simulations.

Material properties from the benchmark, are outlined in Table 1, and the stress/ plastic strain curve is shown in Figure 2. Though not shown, the stress strain curve was extended using a power law fit to the data. Planer anisotropy was not considered, and the average Lankford value (r bar) used was "1".

Table 1: Engineering Material properties

Steel	Coating	Gauge (mm)	0.2% YS (MPa)	UTS (MPa)	UE (%)	TE (%)	n bar*	K*
DP600	HDGA	1.62	403.8	654.2	14.3	23.8	0.159	1040.4

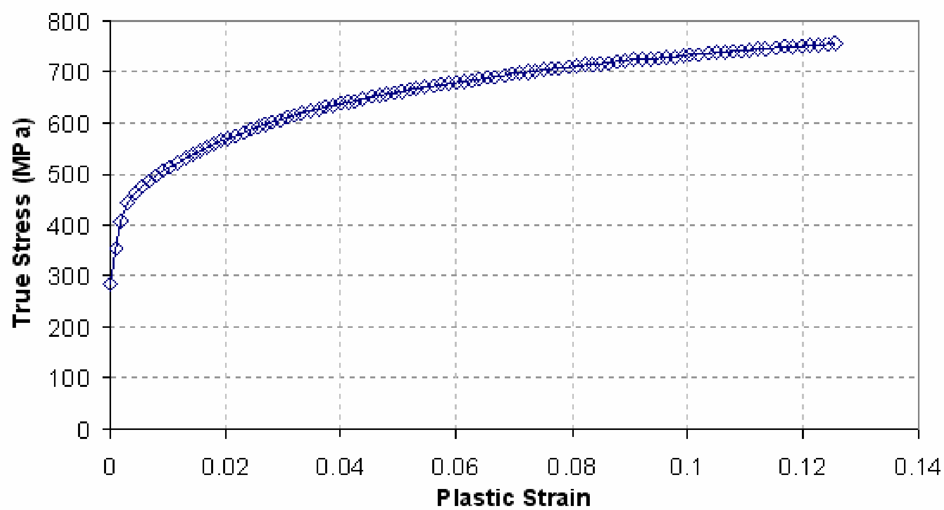

Figure 2: Stress/ plastic strain curve

Design of Experiments and Parametric Study

Four factors/parameters were investigated in the simulation runs. These factors were:

- Factor A – Gaussian Integration points (7 vs. 21),
- Factor B - Coulomb friction (0.5 vs. 0.15),
- Factor C - Implicit finish to the explicit forming simulation (yes vs. no),
- Factor D - Element size (3 adaptive levels vs. 4),

Normally, a full factorial experimental design would require a total of 16 (2^4) forming/springback runs. This was considered to be too costly (CPU intensive). Instead, a fractional design was used. The fractional design chosen was 2^{4-1} resolution VI design. Using this configuration, all parameters (A-D) could be investigated from 8 separate forming/springback runs.

The major assumption used for this approach (and limitation) was that coulomb friction (being a process variable) was expected to have the same effect whether or not an implicit finish was used, or the number of integration points was varied. Using this assumption, the main effects A, B, C, D and the two-factor interactions CD, AC, and AD can be estimated clear of significant confounding. A summary of the simulation runs is shown in Table 2.

Table 2: Summary of Simulation runs

Run No.	Integration Pts. (Factor A)	Friction (Factor B)	Implicit Finish (Factor C)	Number of Adaptive levels (Factor D)
1	7	0.05	no	3
2	7	0.05	yes	4
3	7	0.15	no	4
4	7	0.15	yes	3
5	21	0.05	no	4
6	21	0.05	yes	3
7	21	0.15	no	3
8	21	0.15	yes	4

Forming Simulations Using an Implicit Finish

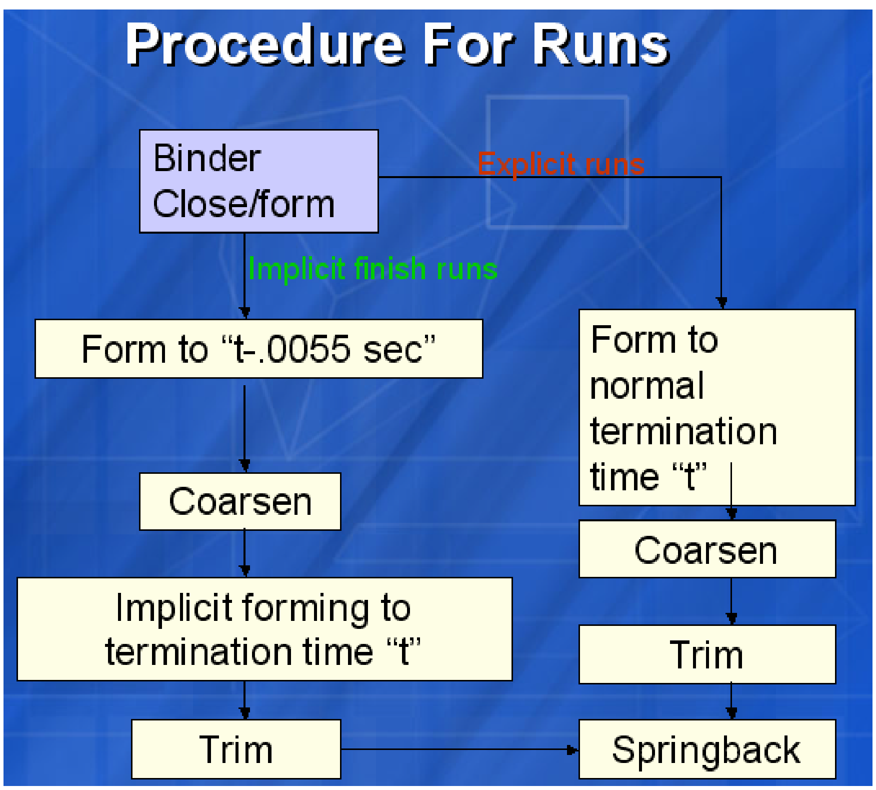

Figure 3: Comparison of procedures for "explicit forming" and "implicit finish simulations".

The procedure for the "implicit finish" and "explicit forming" simulations are shown in Figure 3. Coarsening was performed before trimming in order to aid convergence in the "implicit finish" simulations. For consistency, the same procedure (i.e. coarsening before trimming) was performed for the explicit runs. Problems with elements after trimming, such as incomplete adaptivity constraints, were dealt with using the card "*control_check_shell". Problems such as this can cause poor convergence behavior in the subsequent springback simulations.

Springback Measures

Springback (total displacement) was measured/quantified for the two main sections (sections I and IV), shown in Figure 4 [3]. In addition, the maximum total springback displacement was measured for the entire model. All results were used in the subsequent statistical analysis.

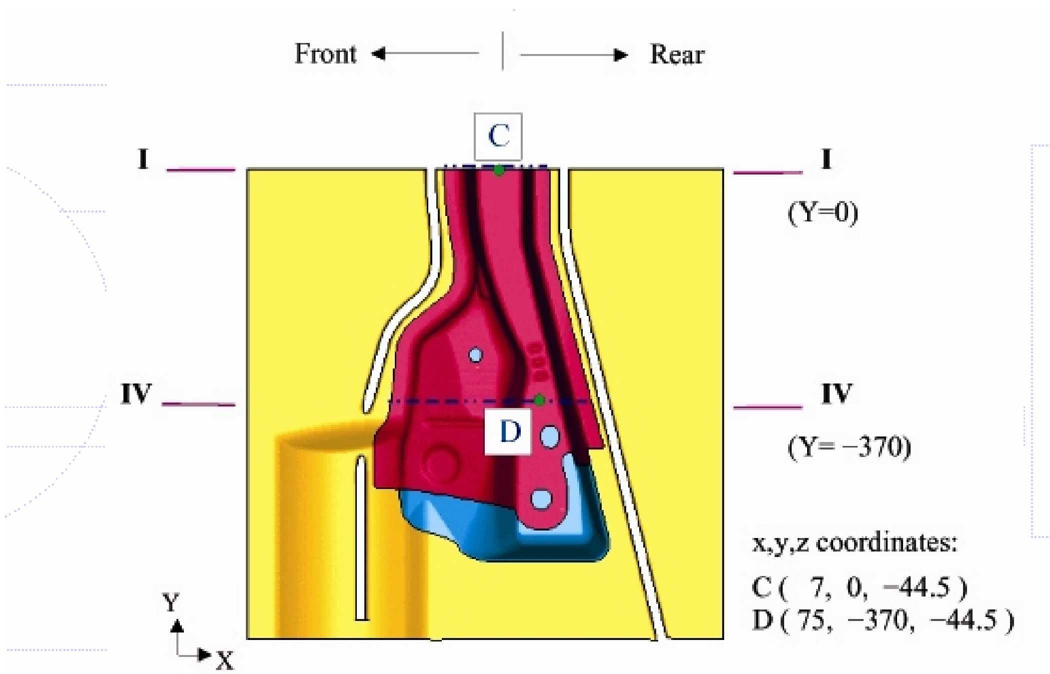

Figure 4: Key sections measured.

Results/discussion

Results for the simulation runs are summarized in Table 3. These were used in the statistical analysis to determine the significance of the factors A,B,C,D. From the analysis, factor B (friction) and factor D (element size or adaptive levels) were significant in terms of the effect on predicted springback. The two main factors A and C were and the two-factor interactions CD, AC, and AD were not significant (Figures 5-9). Since interaction effects were not significant, main effect plots can be used to examine average parameter effects on the predicted springback (Figures 10-14).

Friction Trends (Main Effect):

The effect of friction is shown in Figure 10. The effect of decreasing friction from 0.15 to 0.05 is an increase in“z” displacement on the “front side” and an decrease in “z” displacement on the “rear side”. The location of springback maximum displacement for the entire part is also on the “rear side” (circled in Figure 11). Figure 11 helps to understand these trends. Decreasing friction has the effect of decreasing draw bead restraining forces and forming tension in the plane of the sheet. The result is more “twisting” in the part with lower friction. The part essentially shows upward “lifting” on the front side and “lowering” on the rear side. Overall changing friction changes springback displacements from approximately 18 to 38%.

Implicit Finish to the Forming Simulation (Main Effect):

From the statistical analysis this main effect was not significant. The implicit finish had a small effect, increasing springback by approximately 3% (Figure 12). This may indicate that precautions (such as a trapezoidal velocity profile, the use rigid body stoppers etc) used in the explicit forming analysis to limit artificial dynamics, are sufficient for this part. Another possibility is that the model itself may represent a highly restrained or “stiff ” part, in which the tendency for artificial dynamics is low. An implicit finish may show greater benefits in “less stiff” systems such as the forming of a low gauge outer (skin) panel, or crash forming.

Increasing through thickness Integration points from 7-21 (Main Affect):

This main effect was also found not to be significant. At most, springback increased by about 3% in going from 7 to 21 integration points (Figure 13). This indicates that this part was not sensitive to the increase in integration points. The implication from this is that in general, some parts may not be sensitive to using a large number of integration points. Over time, it may be beneficial to the simulation community to identify classes of parts that may or may not be sensitive to this parameter, or identify appropriate characteristics of parts. For example (as a possible suggestion) on a given part section, the % stretch vs. the % of the section that undergoes bending/unbending deformation could be investigated as a parameter.

Increasing the adaptive level from 3 to 4 (Main Affect):

This effect was found to be significant (Figure 14), and these results are consistent with results from others [7,8]. Increasing the number of adaptivity levels from 3 to 4, had the effect of increasing springback displacement by 20-30%.

Analysis of Section I and IV Springback profiles for all Runs (Table 2):

Figures 15,16 show the resulting springback profiles for sections I and IV, compared to experimentally measured sections provided in the Numisheet2005 proceedings. The results for section IV indicate that springback displacements can be reasonably predicted using the “right” numerical parameters used in this investigation as the experimental profile is within the “band of profiles” from the DOE. On the other hand, the experimental profile for section I is outside of the “band of profiles” on the rear side(Figure 15). The FEA did not adequately predict the “curl” in this area. Other benchmark participants from the Numisheet 2005 proceedings seem to experienced this. Using an improved material model (mixed kinematic/isotropic hardening) could improve the results, however, it may lead to over prediction of springback on the “front side”. At this point the reason for the inability to predict the wall curl on the “rear side of section I” is not known, and may warrant further investigations, for example using different element types.

Summary

Overall, it was found that element size and friction have the greatest effect on the predicted springback and that little is gained by using an implicit finish and 21 integration points through the thickness. This indicates that this part is not sensitive to a large number of integration points. This cannot be generally applied to all parts and further investigation on other parts is warranted.

Also, precautions used in the explicit forming analysis to reduce artificial dynamics seem to be adequate for this part, as there was no significant impact using an implicit finish to the forming simulation. Possible reasons for this are that this part may be “stiff” and formed under highly restrained conditions.

It was also found that despite all combinations of numerical parameters, the wall curl on one side of section I of the Benchmark could not be reproduced, and reasons for this are not known.

Table 3: Summary of springback results (total springback displacement) for the DOE runs at sections I, IV, and maximum springback displacement for the entire part.

Int Pts	Friction	Imp. Finish	Adp. Lvls	Section I		Section IV		
				Front (mm)	Rear (mm)	Front (mm)	Rear (mm)	Maximum (mm)
7	0.05	no	3	4.3706	1.6376	6.5141	6.1353	8.095
7	0.05	yes	4	4.8899	2.5059	8.1874	7.922	10.0599
7	0.15	no	4	3.9627	2.8824	5.2588	8.7559	11.4651
7	0.15	yes	3	3.6076	2.7667	4.9491	8.3127	10.7575
21	0.05	no	4	4.9584	2.6816	8.2494	7.8681	9.907
21	0.05	yes	3	4.6253	1.7572	6.5719	6.7208	8.6887
21	0.15	no	3	3.4235	2.7891	4.05	8.5034	10.7838
21	0.15	yes	4	3.6378	3.4856	5.4564	9.618	11.8603

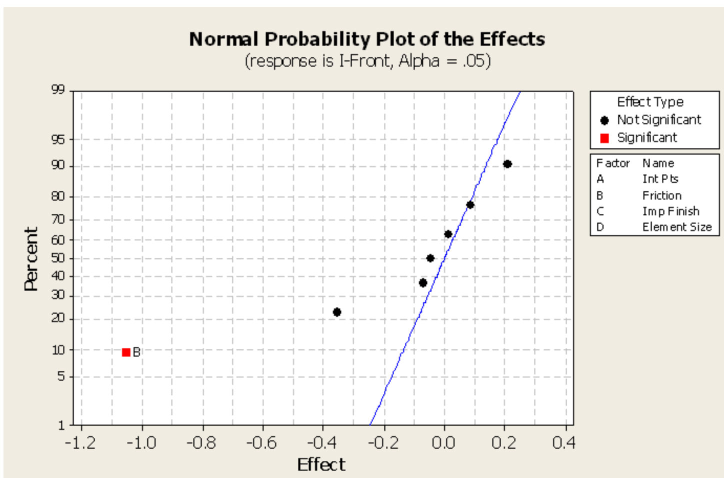

Figure 5: Important/Significant parameters that affect the springback prediction in Section I, front.

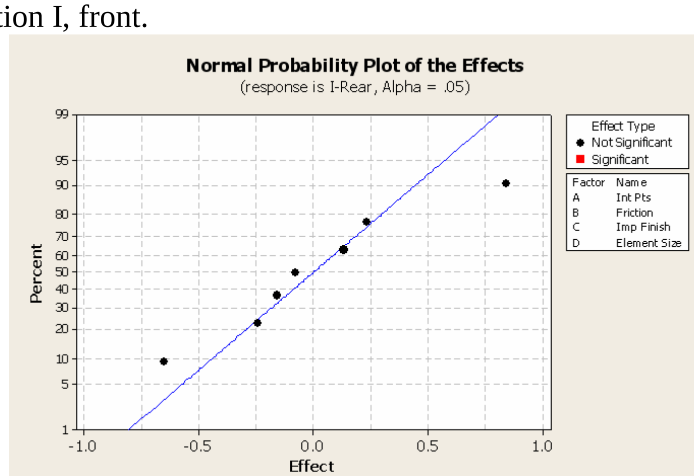

Figure 6: Important/Significant parameters that affect the springback prediction in Section I, rear.

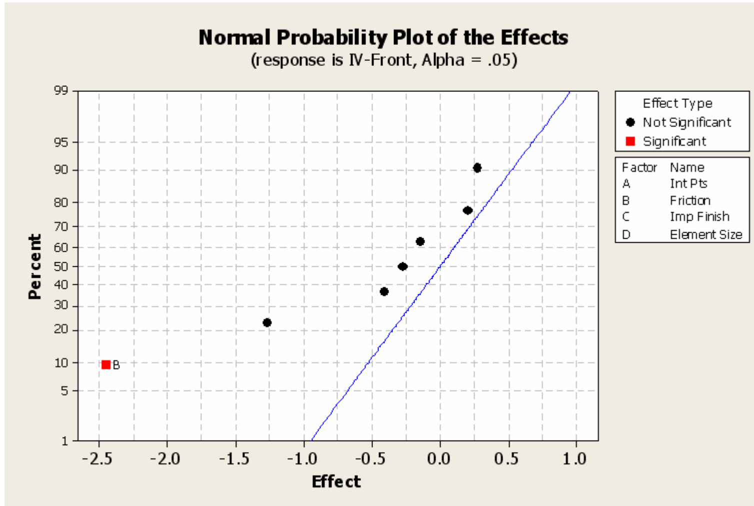

Figure 7: Important/Significant parameters that affect the springback prediction in Section IV, front.

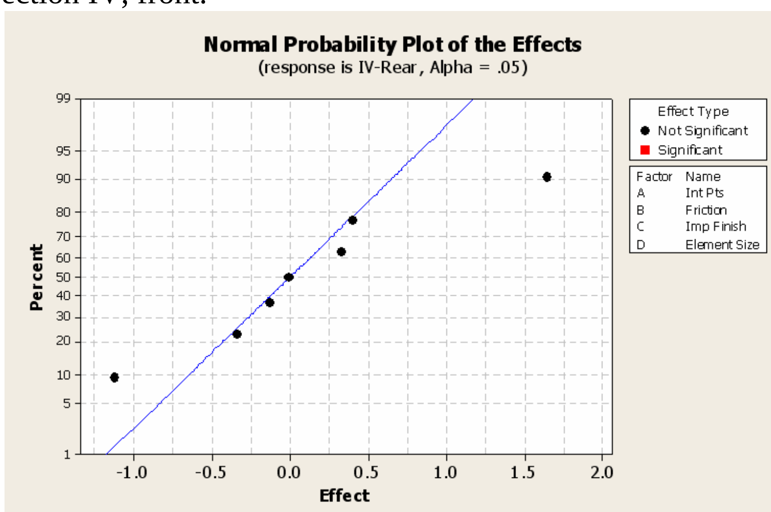

Figure 8: Important/Significant parameters that affect the springback prediction in Section IV, rear

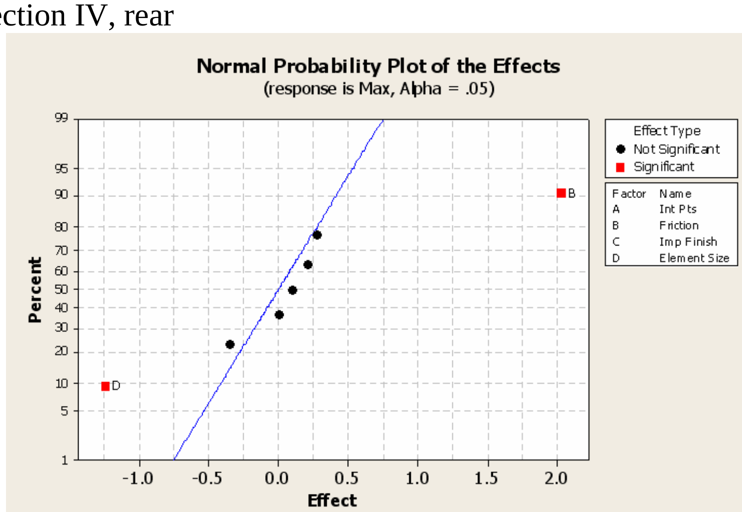

Figure 9: Important/Significant parameters that affect the maximum springback displacement over the entire model.

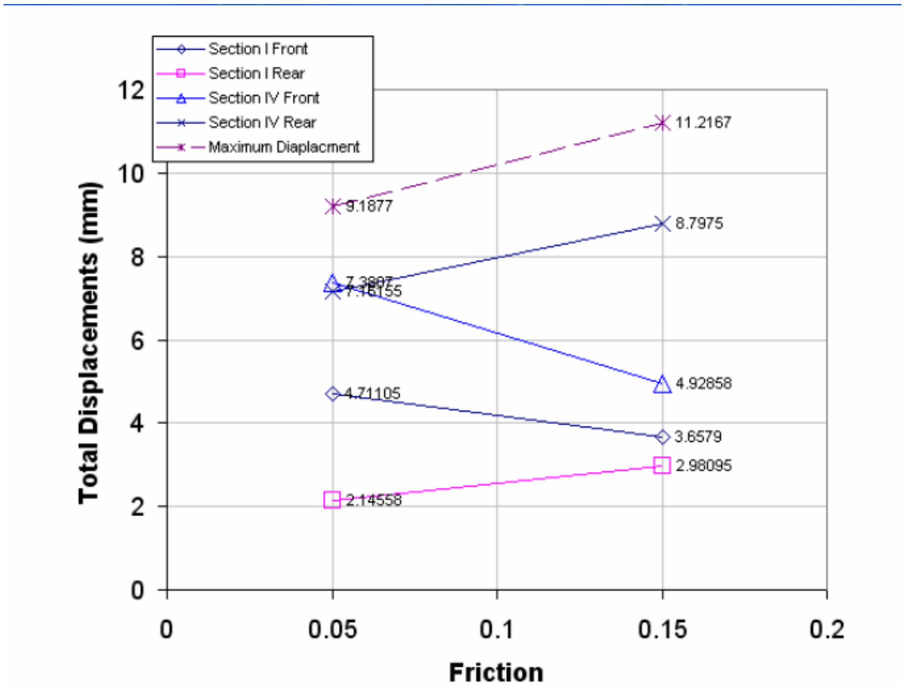

Figure 10: Average effect of friction on predicted springback displacement.

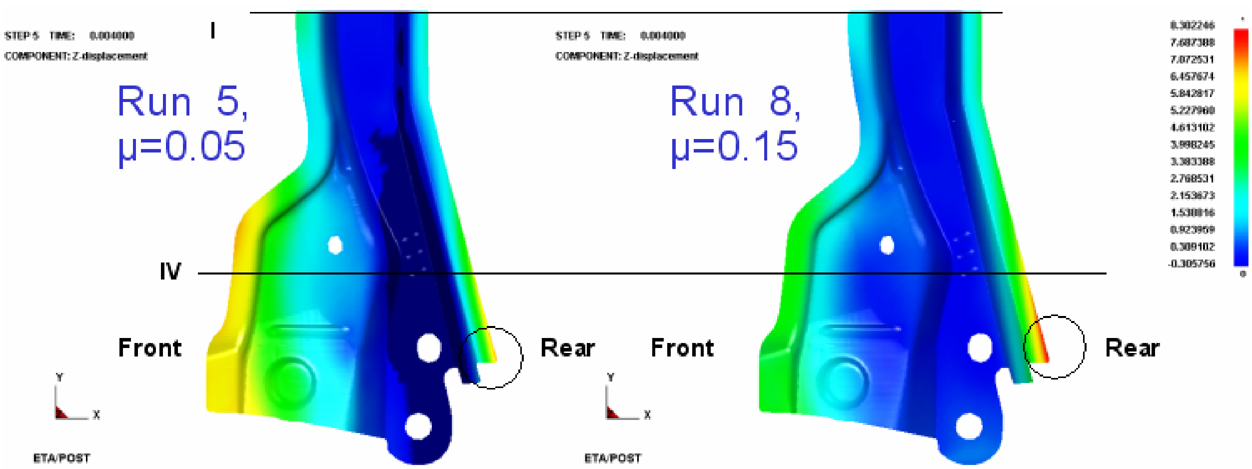

Figure 11: "Z" displacement predicted for comparable runs (Tables 2,3) showing the effect of friction. Decreasing friction from 0.15 to 0.05 results in twisting (i.e. lifting of the "front side", and decrease in z displacement on the "rear side").

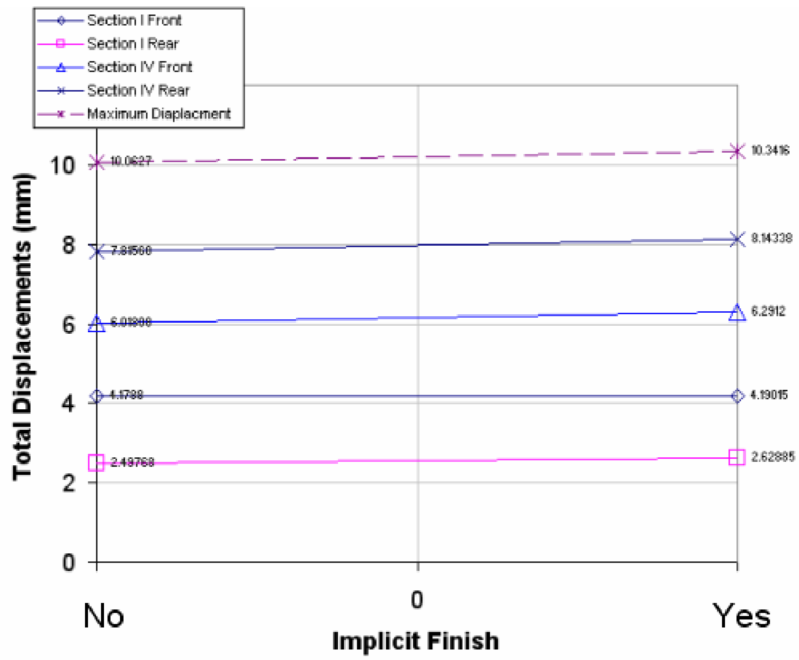

Figure 12: Average effect of an “implicit finish to the forming simulation”, on the predicted springback displacement.

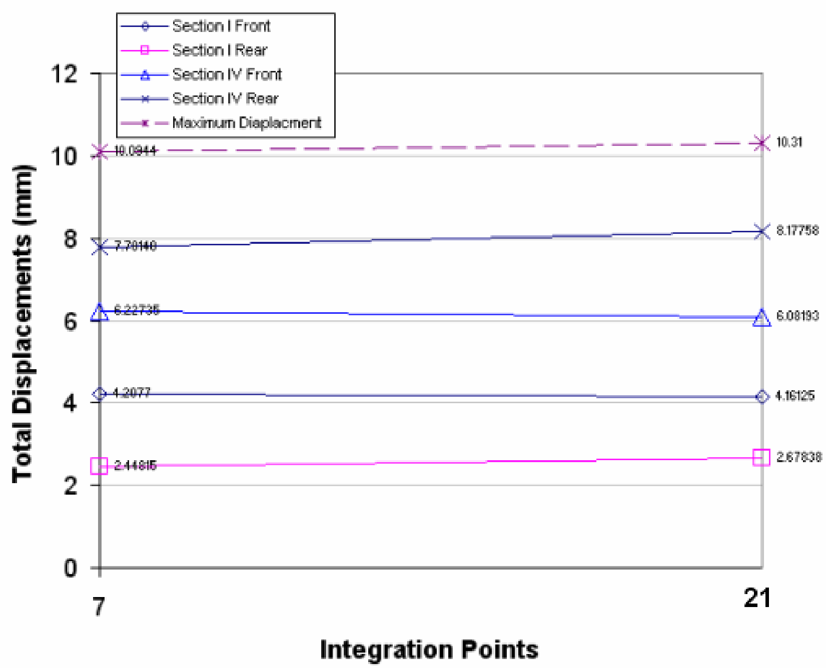

Figure 13: Average effect of “increasing the number of through thickness integration points from 7 to 21”, on the predicted springback displacement.

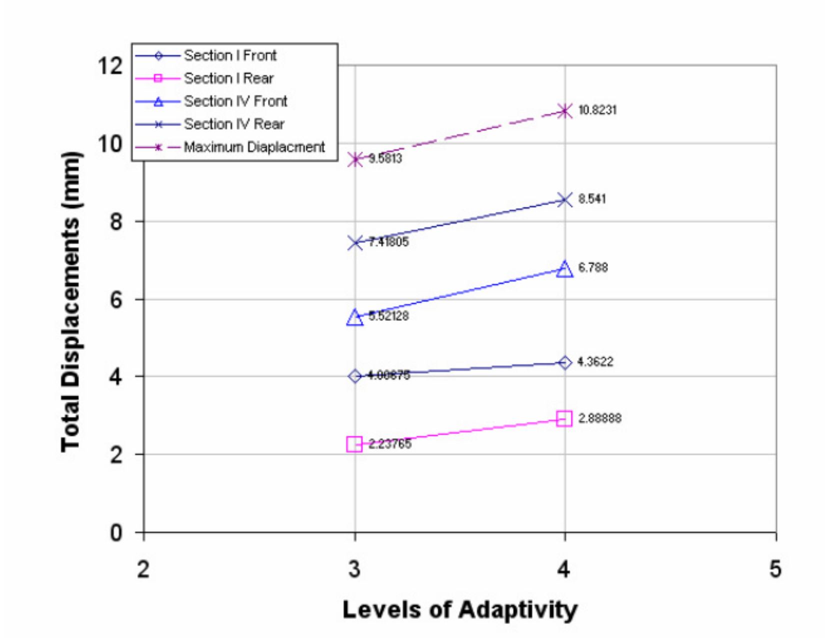

Figure 14: Average effect of "increasing the number of adaptive levels", on the predicted springback displacement

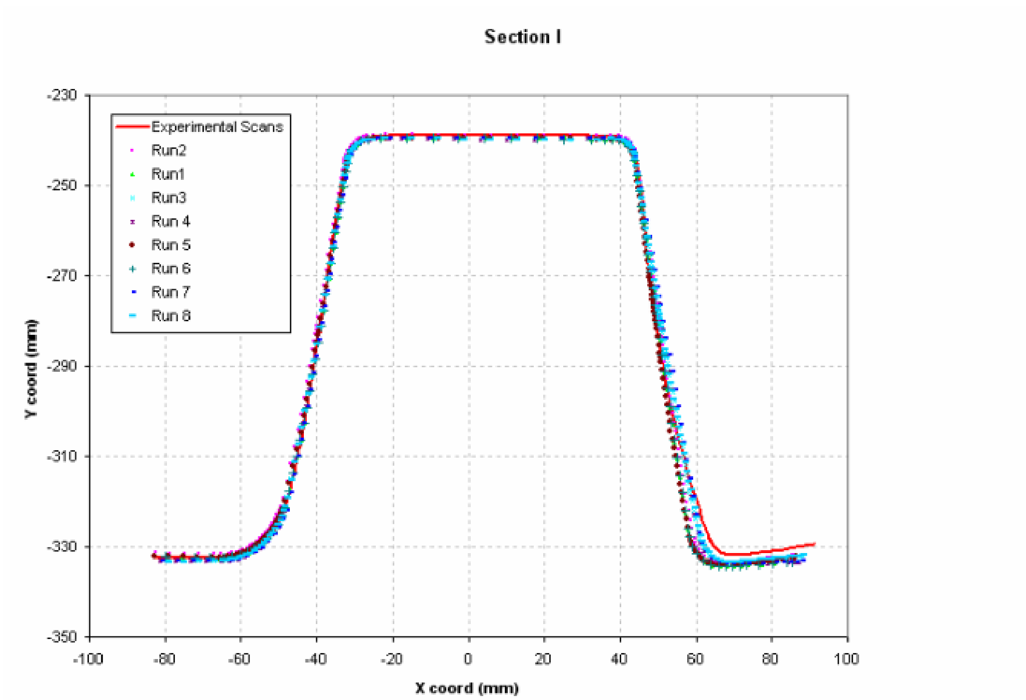

Figure 15: Section I plot containing profiles after springback for runs 1-8 (Table 2) compared to the experimentally measured springback profile from the Numisheet Benchmark proceedings.

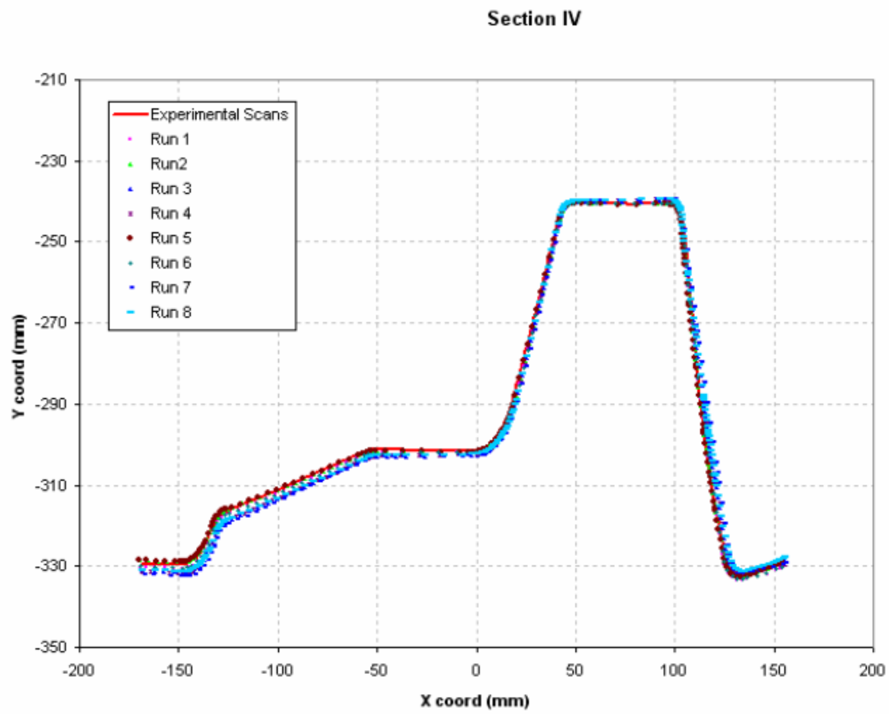

Figure 16: Section IV plot containing profiles after springback for runs 1-8 (Table 2) compared to the experimentally measured springback profile from the Numisheet Benchmark proceedings.

References

1. Li, K. P., Carden, W. P., & Wagoner, R. H. (2002). Simulation of Springback. International Journal of Mechanical Sciences, 44(2002), 103-122.
2. Finn, M. J., Galbraith, P. C., Wu, L., Halloquist, J. O., Lum, L., Lin, T. L., et al. (1998). Use of Coupled Explicit-Implicit Solver for Calculating Springback in Automotive Body Panels.
3. www.numisheet2005.org, and Proceedings for this conference.
4. Maker , B. (1997). Sheet Metal Forming Simulations with LS-NIKE3D (). Livermore, California: Livermore Software Technology Corporation.
5. Maker , B. (September 1998). Implicit Springback Calculation using LS-DYNA. Paper presented at the meeting of the 5th International LSDYNA Users Meeting. Southfield, Michigan.
6. Maker, N. M., & Zhu, X. (2003). A procedure for springback analysis using LS-DYNA. Livermore, California: Livermore Software Technology Corporation.
7. Yao, H., Liu, S. D., Du, C., & Hu, Y. (2002). Techniques to Improve Springback Prediction Accuracy Using Dynamic Explicit FEA Codes. SAE World Congress, SAE2002-01-0159,
8. Lee, S. W., & Yang, D. Y. (1998). An Assessment of Numerical parameters influencing springback in explicit finite element analysis of sheet metal forming. Journal of Materials Processing Technology, 80(81), 60-67.