The Effects of Forming and Parameter Mapping on Further Simulation

Brian Cowell
Tower Automotive Technical Center
3533 N. 27th Street
Milwaukee, WI   53216
(414) 447-4608
cowell.brian@towerautomotive.com

Anthony Kellicut
Tower Automotive

Adam Fisher
Tower Automotive

Keywords:
Crash, Dynain, Hydroforming, Meshing

ABSTRACT

This paper describes the effects of forming simulation results on crash and durability performance and the impact of the method of transferring results from one simulation to the next. Forming simulation may not always result in a mesh that is ideally suited for static or crash analysis. Tower Automotive has developed software to map forming simulation results from the formed mesh to an entirely different LS-DYNA or NASTRAN mesh of the same part.

Simulations of part fabrication represent both hydroforming and mechanical forming. Static simulation is performed in NASTRAN using the work-hardened state as the material input for each element. Other formed parts are subjected to a representative crush load. The effect of transferring results on the same mesh and mapped onto a dissimilar mesh is compared. Results of several crush simulations will be shown, including with forming results, without forming results, and forming results mapped onto a different mesh.

BACKGROUND

Forming operations for metal parts can dramatically alter the material properties of the part. Inclusion of the changes in the properties can be critical for later simulations. LS-DYNA provides a simple means of transferring elemental thicknesses, residual stresses, and plastic strains from one simulation to another, the DYNAIN file. However, it can be somewhat limiting. Basic trimming of the formed part can be done using LS-DYNA or by manually removing elements from the formed mesh. The resulting mesh around holes and edges may not be high in quality. The resulting mesh may not line up nicely for welding of brackets or other components. Having an independent mesh optimized for the next simulation with brackets attached and holes treated properly could improve the accuracy of any simulation, with or without the forming effects considered. By including the forming effects on a well-conditioned mesh, we can get the best of both worlds.

OBJECTIVES

The objective of the study was to discover the impact of parameter mapping on further simulation. The primary focus has been on crash simulation due to the dramatic effect work hardening from forming has on the crash performance of a part, as shown previously [1].

APPROACH

A hypothetical hydroformed frame rail crush initiator was used for the crash study. Expansion was 7.9%. The material used was mild steel with a yield point of 296 Mpa (43 ksi). The rail section measured roughly 51 mm (2”) wide by 152 mm (6”) tall by 305 mm (12”) long. Forming simulations were conducted with two different element densities. Adaptive remeshing was not employed. The coarse tube model had 2,500 elements and the fine model had 10,000 elements. Minimum thickness after forming was 2.58 mm with the coarse model and 2.55 mm with the fine model. The mapping target mesh had 5,156 elements. The DYNAIN files from the coarse and fine forming simulations were mapped onto the map target mesh. The original DYNAIN meshes, the two mapped meshes, the map target mesh, and the DYNAIN mesh shapes without forming effects were then impacted by a rigid plate. The plate had a mass of 170 kg and an initial velocity of 11.2 m/s (25 mph). Figures one and two show the thickness distribution after forming of the coarse and fine mesh models. The finer model thins out slightly more in the corners because it stretches to fill the form better than the coarse elements can. Figures three and four are the effective plastic strain after forming. Again, the finer model peaks more in the corners than the coarse mesh because it fills the tool better. The residual stresses also correspond quite well, as shown in figures five and six. The lighter appearance of the fine forming figures is due to the higher density of white element edges, most notably in figures seven and eight. Those figures also demonstrate that the crush mode of the coarse and fine forming meshes is the same.

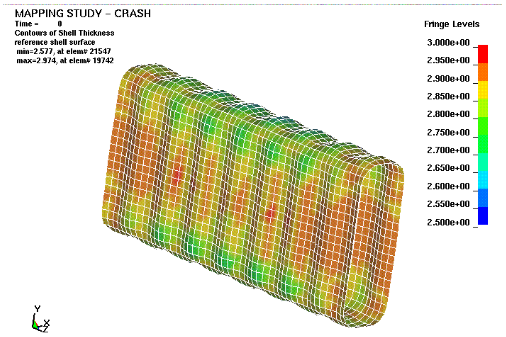

Fig 1. Coarse Forming Thickness

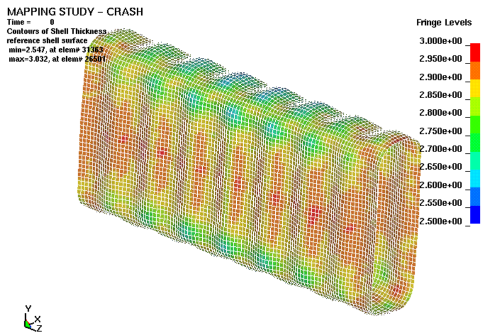

Fig 2. Fine Forming Thickness

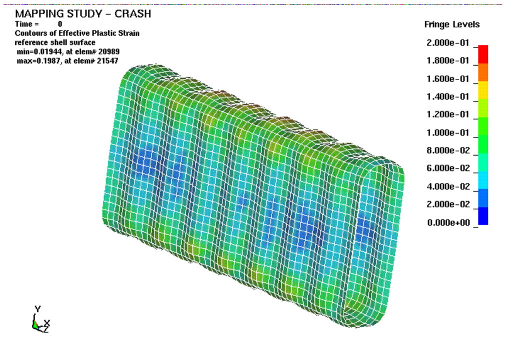

Fig 3. Coarse Forming Plastic Strain

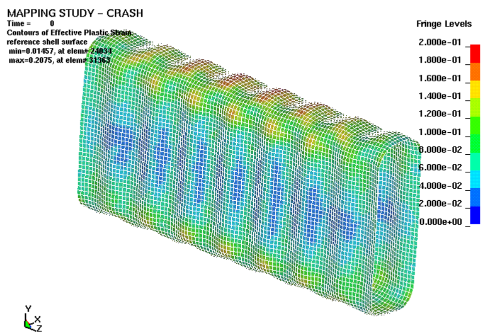

Fig 4. Fine Forming Plastic Strain

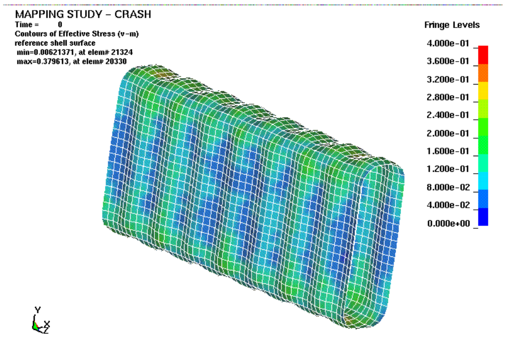

Fig 5. Coarse Forming Residual Stress

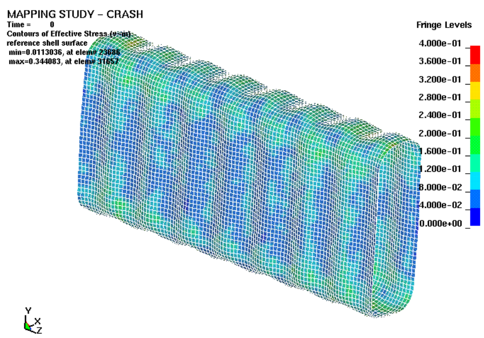

Fig 6. Fine Forming Residual Stress

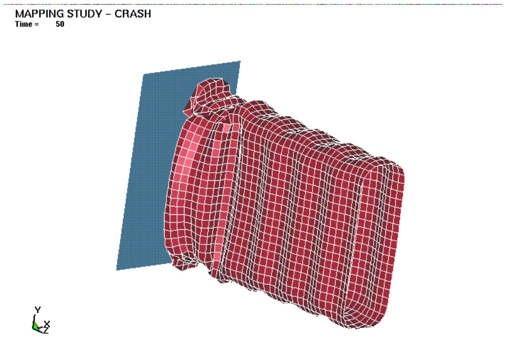

Fig 7. Coarse Forming Crashed Shape

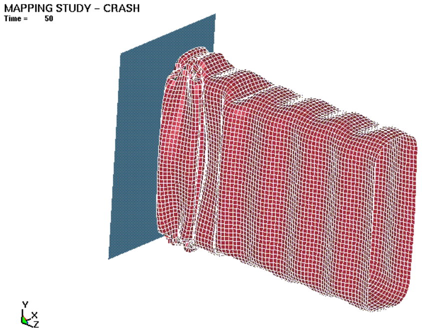

Fig 8. Fine Forming Crashed Shape

RESULTS

The position of the impacting plate over time was plotted for each case. Figures nine and ten show the crashed shape of the coarsely and finely meshed forming simulations. The mapping target shape and shape resulting from the forming simulation were also subjected to crash without initial thickness changes, residual stresses, or plastic strains. The results of the mapped models closely match those of the DYNAIN model. The maximum displacement variance from the DYNAIN performance is 2.2% for the coarse forming model and 1.4% for the fine forming model. The mapping target mesh performs quite differently than the formed shape when crashed without forming effects. Adding the effects of forming to the two meshes make them behave nearly identically.

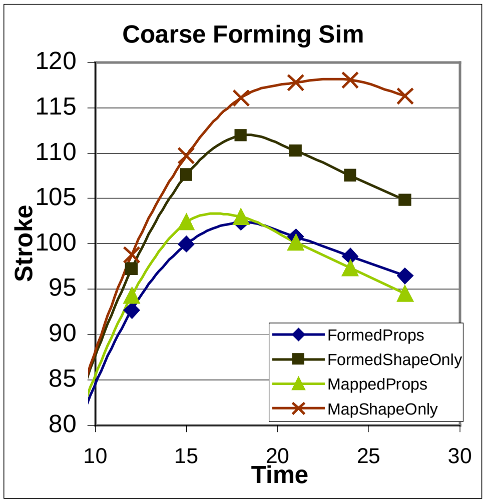

Fig 9. Coarse Forming Mesh Results

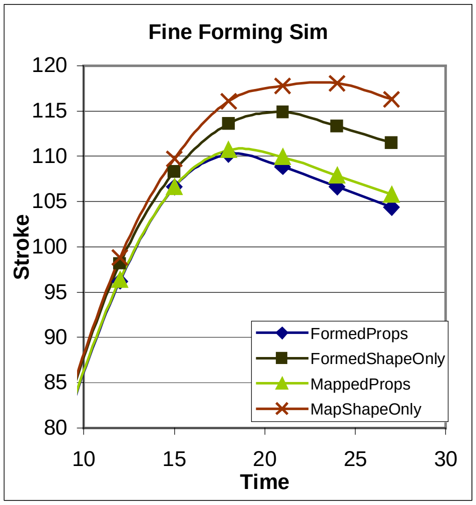

Fig 10. Fine Forming Mesh Results

NASTRAN APPLICATION

The customized software developed by Tower Automotive can export the elemental thicknesses from forming simulations into static stiffness and modal models. The impact of assigning thickesses elementally rather than by manually assigning groups is likely to vary on a case-by-case basis. Mapping of residual stresses into NASTRAN is a future phase of the development of Tower Automotive's software. What was examined here is the ability to look at stresses as a percentage of the formed yield strength of the material. In general, areas thinned out from forming have higher stresses under loading but also have higher yield points. By looking at the percent yield on an elemental basis, thin areas under high stress do not raise as much concern because the altered material in those areas can handle the higher stresses. In this particular example, the hardening effects do not adequately compensate for localized stress concentrations. The maximum ratio of stress to yield is 1.91. The worst-case ratio areas are less concentrated than the maximum stress areas, as demonstrated by the difference in figures eleven and twelve. Figure thirteen shows the yield stress after forming of the hydroformed engine cradle component.

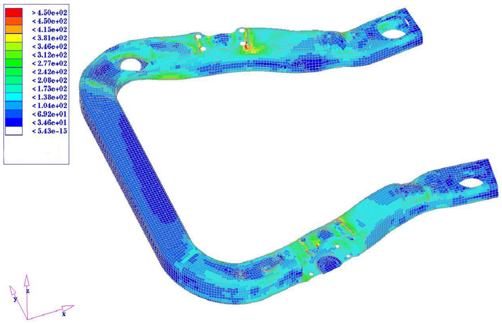

Fig 11. Von Mises Stress

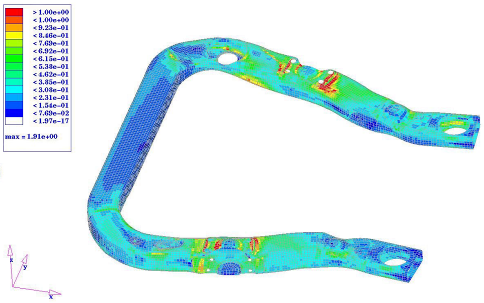

Fig 12. Ratio of Von Mises/Yield Stress

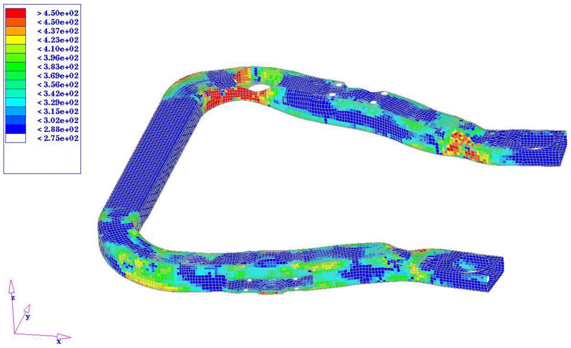

Fig 13. Formed Yield Stress

CONCLUSIONS

The mapping of forming simulation results onto meshes for subsequent simulations improves accuracy over conventional shortcuts and saves time over current result transfer methods. The impact on crash simulation for systems with extensively formed materials, whether hydroformed or stamped, is significant. If many crash simulations are needed to determine the impact of material or thickness changes, incorporating the results of the preceding forming simulations is now relatively easy. Reattachment of adjoining parts is no longer needed. One mesh can be prepared for all simulations and have the forming results applied to it. The implications with regard to NASTRAN simulation may not be as significant at this time, but the incorporation of elemental thicknesses today and residual stresses in the future can only help to improve the accuracy of finite element simulations. By improving the accuracy of static and crash simulations, fewer prototypes may be needed, reducing development cycle time.

ACKNOWLEDGEMENTS

We would like to thank Karl Monis of Tower Automotive for his work on the NASTRAN aspect of the project and Anna Wei for her valuable assistance in testing the software. Finally, we would like to thank our leaders at Tower Automotive for their patience in allowing us to work on this unusual project.

REFERENCES

1. DUTTON T., IREGBU S., STURT R., KELLICUT A., COWELL B., AND KAVIKONDALA K. (1999), “The Effect of Forming on the Crashworthiness of Vehicles with Hydroformed Frame Siderails”, SAE

2. LSTC (1997), “LS-DYNA User’s Manual Version 940”, Livermore Software Technology Corporation