THE INFLUENCE OF RESIDUAL EFFECTS OF STAMPING ON CRASH RESULTS

Trevor Dutton, Paul Richardson, Andrew Knight and Richard Sturt
Ove Arup & Partners
The Arup Campus, Blythe Gate, Blythe Valley Park
Solihull, West Midlands, B90 8AE

Tel: +44 (0) 121 213 3301
Fax: +44 (0) 121 213 3302
Email cae@arup.com

ABSTRACT

The thickness changes and work hardening arising during the forming process are generally ignored in crash analysis. However, LS-DYNA offers a number of options for quantifying these effects. This paper sets out some recommended methods, and quantifies the effect of the forming process on crash response of a typical car of stamped steel construction. LS-DYNA can also be used for accurate stamping simulation, but in this study a one-step code was used, with the aim of finding the fastest method of generating and including the stamping data. The trade-off between the time taken and accuracy is examined.

INTRODUCTION

Material data derived from tensile tests is an important input to finite element crash models. However, the test samples are normally taken from the coil, not from formed parts. The forming process is likely to modify the properties of the materials due to work hardening; thickness changes and residual stresses may also be important. This could lead to errors in predictions of crash response.

The degree of effect on the crash behaviour depends on the type of forming process. The hydroforming process leaves very significant residual thickness changes and work hardening, and can have a major effect on crash results [1]. Even the predicted principal mode of collapse can be altered. This is because some areas of the part are both thickened and work-hardened by the hydroforming process, leading to a considerable increase of strength and hence increased resistance to collapse in those areas.

Stamped parts are thought to show less sensitivity, because areas that are work hardened would also in general be thinned by the stamping process; the two effects might approximately cancel each other. Experimental studies on axially crushed straight box sections [2] did not show an observable effect from the forming process: any effect was within the experimental scatter, and may be less significant for the geometries tested. An analytical study based on the high strength steel materials in the ULSAB vehicle [3] showed that residual stamping effects have some influence on the deceleration time history but no change of deformation mode was observed. Compared with other approximations in the crash models, the effects of forming might be considered to be secondary. That conclusion is also drawn by the work reported here. However, given the drive to reduce prototypes and place an ever-increasing reliance on CAE, it would not be prudent to ignore the possibility of more significant influence in some cases.

One barrier to the routine, efficient inclusion of residual forming effects in crash models is the time and resource involved in preparing the stamping models and then transferring the data into the crash model. While it is increasingly common to perform full finite element stamping simulations on car body panels, the availability of results from the forming simulations does not always coincide with the demand from the crash analysts. Therefore it is necessary to consider methods whereby the forming

data can be generated quickly on demand, using the information available to the crash analysts. This paper outlines a variety of such methods and quantifies the time versus accuracy trade-off for a sample panel. Methods of mapping the forming data into the crash model are described.

MODEL DESCRIPTION AND METHOD

Base Crash Model

The base crash model is the Chrysler Neon LS-DYNA model developed by NCAC [4], Figure 1.

For the purposes of illustrating the principles involved, the body panel material data has been replaced throughout with mild steel. Stress-strain properties were derived from tensile test. The change was made because the high strength steels in the original NCAC model showed little strain hardening and hence the effects of the forming process might be underpredicted compared with other typical vehicles. For this reason, the crash results reported here should not be considered indicative of the performance of the original NCAC model nor of the Chrysler Neon.

The impact conditions are 35mph into a flat rigid wall. The model was run in LS-DYNA 950e [5].

Figure 1. NCAC Chrysler Neon Model.

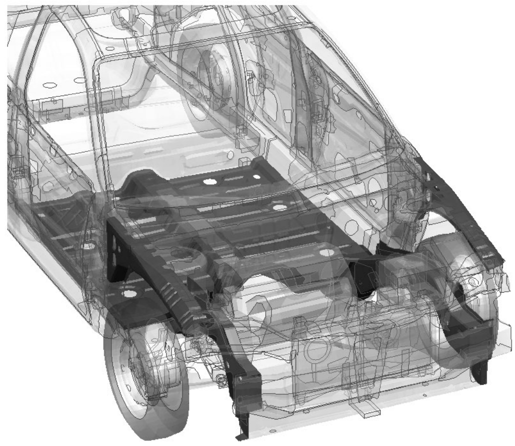

Figure 2. Panels for stamping analysis

The panels absorbing the most energy in the base crash model (Figure 2) were selected for stamping analysis.

Base Stamping Simulation Method

The forming results were generated by FAST_FORM3D [6], a one-step reverse stamping simulation program. The mesh from the crash model was used as input. The objective was to test the simplest method by which forming results could be generated, so no attempt was made to add fillet radii, remove undercut conditions, or otherwise make the crash mesh more suitable for forming analysis. However, it was necessary to fill holes and eliminate notches in free edges. In some cases a curved blankholder surface was automatically generated in order to create more representative forming conditions. An automatic method to rotate the panel into an orientation suitable for press forming was used to ensure a balanced operation and minimise (but not necessarily eliminate) undercut. Initially, the boundary conditions were taken as fixed at the perimeter of the panel; the forming limit diagram was studied and revisions made to the boundary conditions until a successful forming operation was indicated, i.e. a strain distribution in the formed panel that indicated neither splitting nor severe wrinkling tendency.

Because the same mesh is used for stamping and crash, no data mapping is necessary. The thickness and plastic strain are simply reformatted from the stamping model results into *ELEMENT_SHELL_THICKNESS and *INITIAL_STRESS_SHELL cards, which are then included in the LS-DYNA crash model input. Element IDs match in the stamping and crash simulations. The next release of FAST_FORM3D will output LS-DYNA format data directly, avoiding the need for reformatting. Residual stresses have been shown by previous studies [1] to be less significant and were not considered.

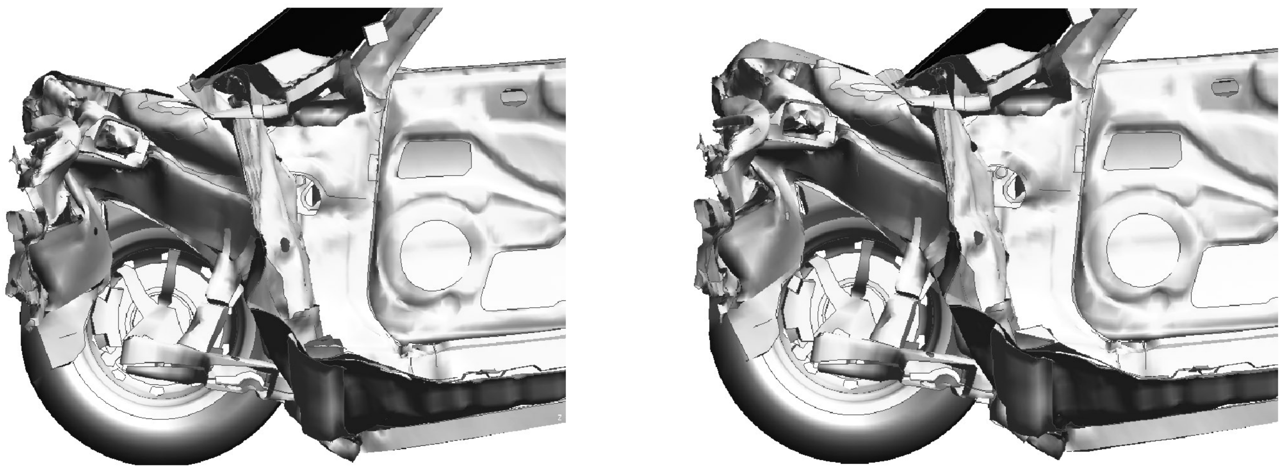

Figure 3. Deformation of front structure without (left) and with (right) stamping effects

RESULTS

Deformations of the front structure from the analyses with and without the stamping effects are compared in Figure 3. There is no significant change of deformation mode.

When the stamping effects are included the peak B-pillar deceleration pulse is reduced from 45.8g to 42.1g (Figure 4). The average acceleration between 40 and 70 milliseconds, when influence on occupant injury is likely to be greatest for this crash case, is reduced from 37.1g to 35.6g. The peak force carried by the sidemember (Figure 5) is 18% higher; the extra energy absorbed early in the crash explains the subsequent reduction in peak deceleration.

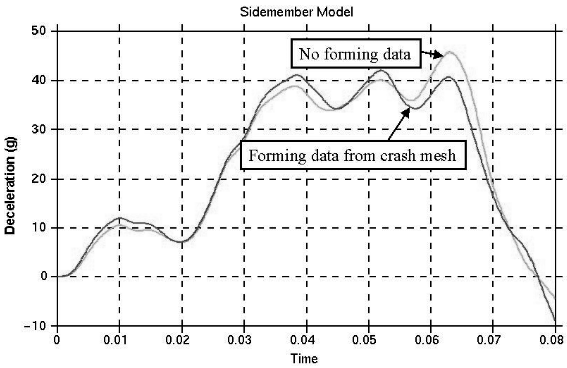

Figure 4. B-post deceleration pulse.

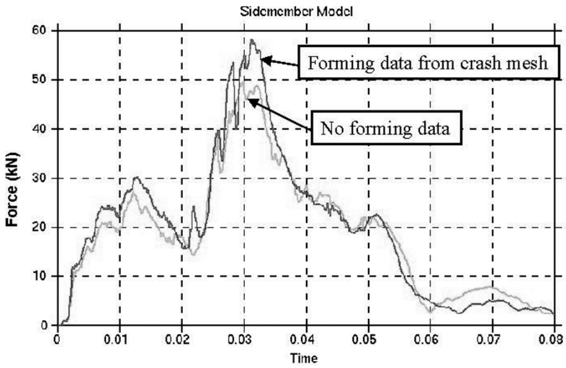

Figure 5. Sidemember force.

Discussion

Overall, the differences arising from the inclusion of forming effects is significant but probably less so than the effect of other approximations in the model, for example the data used to account for strain rate enhancement of material properties. However, the degree of difference observed in the sidemember force histories could potentially lead to changes of collapse mode in other vehicle geometries or in other crash types. Given the increased reliance on CAE in place of physical testing, it would be prudent to include the stamping effects in future crash analysis work despite the relatively modest differences in overall response shown here.

The effect of forming on strain rate enhancement has been ignored in this study. This is justified by experimental work [7], indicating that the strain rate sensitivity of yield stress is independent of pre-strain.

The one-step stamping simulations could be carried out by a crash analyst, given suitable training. The time taken is about 30 to 60 minutes per panel. It would be practical to include this as part of a general crash modelling process, and the timing of the stamping simulations would not have to coincide with the manufacturing feasibility and process engineering development.

STAMPING SIMULATION: ALTERNATIVE APPROACHES

Intermediate method: fine stamping mesh with one-step method

The base method may contain inaccuracies arising from the relatively crude mesh and geometry. For example, omission of fillet radii would artificially increase the path length of the section, and sharp angles between elements may cause spurious bending effects. To test this, a detailed mesh was created and re-analysed using FAST_FORM3D. Because of the provenance of the model, geometry data to create the detailed mesh had to be created, starting from the crash mesh but with the surfaces smoothed, fillet radii added, undercuts and pierced holes removed. The finely meshed stamping model of the sidemember panel and the equivalent panel in the crash model are shown in Figure 6.

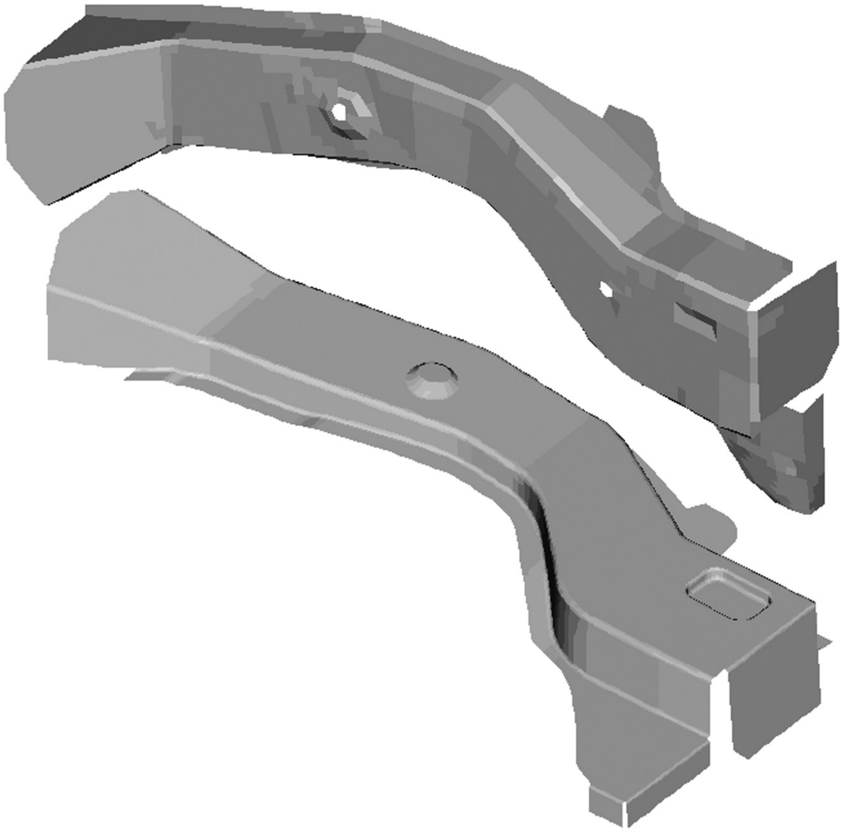

Figure 6. Crash model and Stamping model.

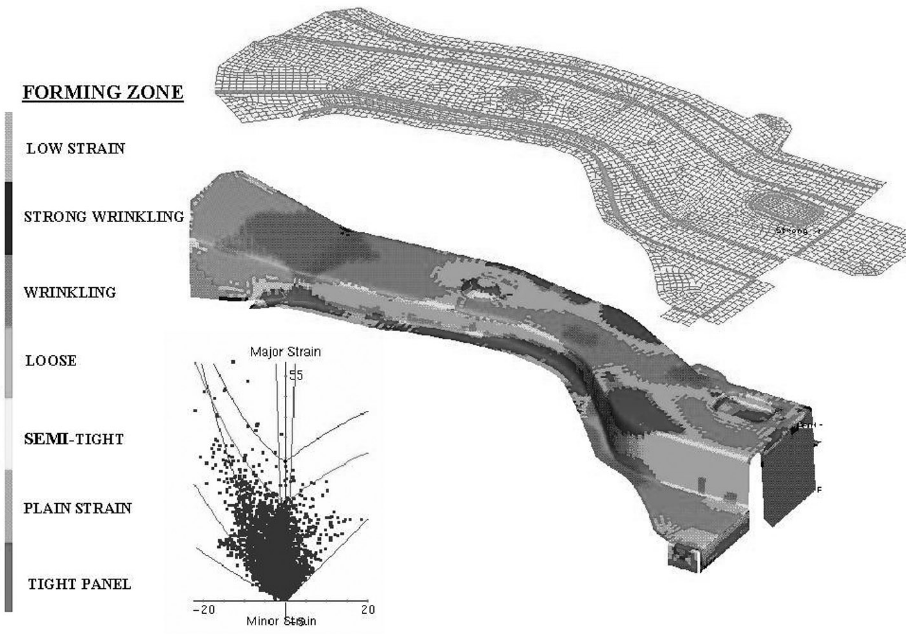

Figure 7. Stamping results from FAST_FORM.

The forming results (Figure 7) were mapped into the crash model using Oasys Primer [8]. Local axes are set up to orient the stamping model such that it overlays the equivalent part in the crash model, by defining three pairs of equivalent nodes. The crash model then receives thickness and plastic strain from the nearest element in the stamping model. This simple algorithm is sufficient provided that the stamping results are sufficiently smooth; large variations within one crash model element would lead to unreliable mapping. The mapping process can be completed in about two minutes per panel, including reading in the stamping model, defining the local axes and visually checking the results of the mapping. A sample of the mapped data is shown in Figure 8.

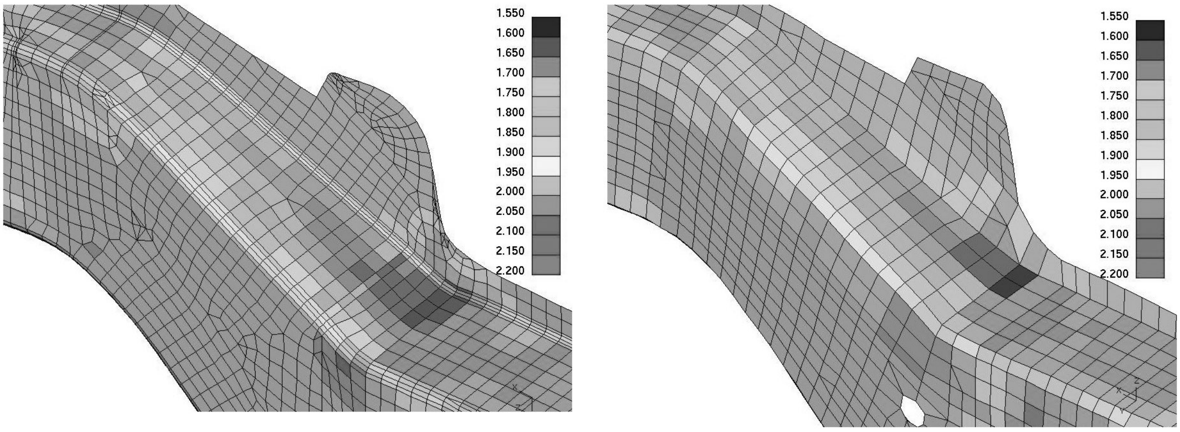

Figure 8. Mapping of thickness from the stamping model (left) onto the crash model (right).

In version LS960, it will be possible to map the data within the input stage of LS-DYNA, using *INCLUDE_STAMPED_PART. The local axes are chosen by an identical three-node method, but visual checking of the mapping results can be performed only after initialisation of the model.

The difference in stamping results arising from the more detailed mesh at a typical section is shown in Figure 9. The results are significantly different.

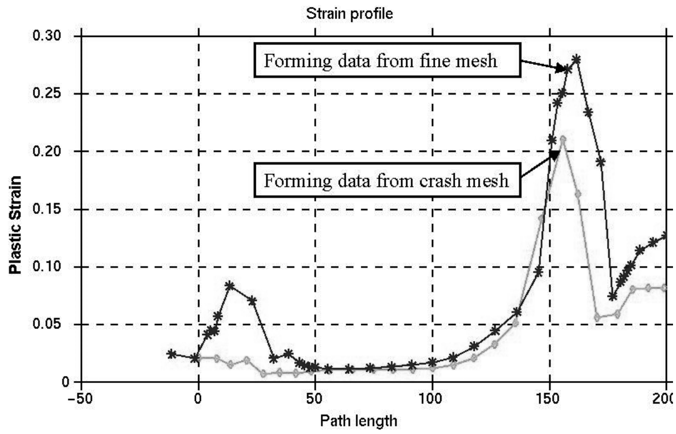

Figure 9. Plastic strain at X=650: crash mesh v fine mesh.

Investigations were carried out using a model consisting of the sidemember only (Figure 10). The predicted force histories in the sidemember are compared in Figure 10, firstly with no stamping effects, then with the base method in which stamping effects are calculated using the crash mesh, then with the stamping data derived from the fine mesh. Considering the significant differences in the forming results, the differences between the latter two crash models are surprisingly small. For the panel considered here, the quicker base method is adequate. In normal circumstances detailed part geometry would be already available, in which case the total time required per panel is between 40 and 80 minutes (10 to 20 minutes extra compared to the base method). In this case, however, it was necessary to re-create the geometry, and the time taken was approximately 5 hours.

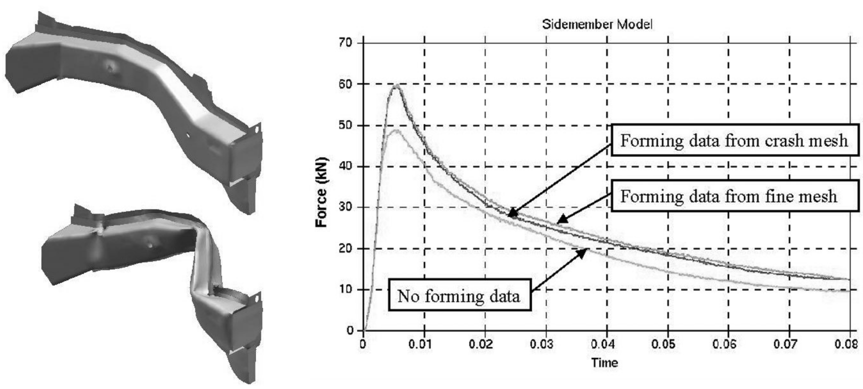

Figure 10. Sidemember model and effect of forming data

Most accurate method: detailed finite element analysis

The one-step method assumes a linear path between initial and final geometries. For many panels, the errors arising are not significant. However, the inability to capture path-dependent effects, such as the sequence of contact with the tooling at re-entrant steps, might lead to strains being underestimated. These potential errors would be eliminated by a detailed LS-DYNA analysis of the stamping process.

To carry out such an analysis rigorously would require development of a representative forming process (for example, draw, restrike, flange, trim and pierce) together with tooling surfaces for each operation. It is possible for an engineer experienced in stamping simulation to develop a model of at least the initial draw operation from the final part geometry, using CAD tools to unfold any undercut areas. Forming simulation programs are beginning to offer blankholder surface and addendum generation functions to speed up the creation of a tool design model. While such functions are reducing the time needed to create a detailed LS-DYNA model, it is likely that several iterations would be needed to achieve a satisfactory result – for example, varying the blankholder force, edge/drawbead conditions, blankholder and addendum geometry. The total time required to analyse each panel by this method is likely to be between one and five days.

In view of the time required to analyse each panel and the large number of panels, it would be impractical to carry out such analyses purely for the purpose of deriving residual thickness and plastic strain for the crash model. However, where these models already exist, they would be the preferred source of data due to the increased accuracy inherent in the LS-DYNA method.

SUMMARY OF RECOMMENDED TECHNIQUE

If stamping results are not already available:

- One-step stamping analysis using the crash mesh without changing element ID
- Fill holes, iterate boundary conditions to achieve a feasible stamping
- Convert thickness results to *ELEMENT_SHELL_THICKNESS
- Reformat the plastic strain results into *INITIAL_STRESS_SHELL cards, setting the stresses to zero

If detailed stamping models are already available:

- From the results, create an LS-DYNA keyword file with *ELEMENT_SHELL_THICKNESS and *INITIAL_STRESS_SHELL (this can be done by including *INTERFACE_SPRINGBACK_DYNA3D_THICKNESS in the stamping model).
- Map the data onto the crash models using Oasys PRIMER or *INCLUDE_STAMPED_PART in LS960.

CONCLUSIONS

- Inclusion of residual stamping effects did not change the collapse mode in the crash model analysed here. However, the collapse load of the sidemember increased by 18% and the maximum deceleration reduced by 3.7g.
- There is potential for residual stamping effects to cause more significant differences in overall crash response, therefore they should be included in crash models.
- The necessary data can be generated efficiently with the one-step reverse stamping simulation method, using the crash model mesh, taking 30 to 60 minutes per panel. This could be done by a suitably trained crash simulation engineer, although the forming results should not then be taken as final confirmation of manufacturing feasibility.
- The 10 to 20 minutes additional effort involved in preparing a more refined mesh for the one-step stamping simulation leads to significantly different stamping results, but the crash results were unaffected. There is insufficient evidence at present to recommend refining the mesh for the stamping simulation.
- LS-DYNA stamping simulations would be the ideal source of data if already available. To create the data by this method would take 1 to 5 days per panel. An experienced process engineer would be needed if this method were followed.

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