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Steel Processing Effects on Impact Deformation of UltraLight Steel Auto Body

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ABSTRACT

The objective of the research presented in this paper was to assess the influence of stamping process on crash response of UltraLight Steel Auto Body (ULSAB) [1] vehicle. Considered forming effects included thickness variations and plastic strain hardening imparted in the part forming process. The as-formed thickness and plastic strain for front crash parts were used as input data for vehicle crash analysis. Differences in structural performance between crash models with and without forming data were analyzed in order to determine the effects and feasibility of integration of forming processes and crash models.

INTRODUCTION

New High Strength Steel (HSS) materials and processes are increasingly used in today's automobiles in order to reduce weight and improve performance. One challenge posed by these steels is that they deform differently from mild steels to which many component manufacturers are accustomed [2]. High strength steel stampings have greater springback and require different draw angles, and each different grade must often be treated by the design and manufacturing engineers as a unique material. Forming processes have to accommodate higher strength and thinner sections of HSS and result in same or better quality of the final part while reducing costs. Shapes are not becoming any simpler, either, fueled by the designs that are constantly challenging manufacturing feasibility. Computational modeling of stamping [3-5] and crashworthiness [6] has been generally considered as two separate engineering disciplines. Stamping of automotive panels results in significant strain hardening and thinning in the formed parts. It is generally assumed that plastic hardening offsets the reduction in thickness and, consequently, that crash simulations can be carried out using properties of the virgin coil. Recent publications [7, 8] have shown that sheet metal forming has measurable effect on impact performance of automotive components. Forming integration into structural performance models has also been considered for other applications (see for example References 9, and 10). Even though the forming effects have been observed to have important effect on a component level, the effects on the entire vehicle have not been clearly demonstrated. The reasons for that are multifold. Current crash modeling technology employs numerous approximations, and the forming influence may be of a secondary nature in the crash models. The discrepancy in the level of detail between forming and full vehicle crash models can mask the effects that forming has on the vehicle response level. The stamping models can afford finer Finite Element Method (FEM) discretizations and when the forming results are averaged and mapped into coarser crash models, the local stamping variations can be lost. Forming effects will certainly be more apparent for lightweight structures that have been extensively stretched during forming and for materials with rapid strain hardening, such as Dual Phase and TRIP steels. Finally, the multitude of styles in modern vehicle designs and their crash absorbing structures makes developing definite quantifiers of forming influence on crashworthiness a futile task. However, trends can be examined and may lead to identification of needed improvements in modeling technology. Incorporation of stamping effects has to show clear effects on crash performance model responses in order to justify increased model complexity and effort.

The paper outline is as follows: in the following section, ULSAB model and materials used in the original design are briefly described. Forming of crash relevant vehicle components is presented next. Then, crash simulation results for models with and without forming effects are analyzed using comparison of global vehicle response and individual structures. The conclusions of the research are stated in the final section.

ULSAB CRASH MODEL

ULSAB, shown in Figure 1, is a lightweight vehicle design that uses HSS and ultra HSS for more than 90 percent of the body. ULSAB also utilizes new technologies such as hydroforming, tailor-welded blanks (TWB), steel sandwich materials and laser welding. Modeling of the vehicle using advanced material models has been investigated in Reference 11 where additional references on the ULSAB project can be found. The ULSAB crashworthiness under numerous car-to-barrier impact scenarios has been reported in Reference 1, and crash compatibility between ULSAB and existing vehicle designs have been investigated in Reference 12.

Figure 1. ULSAB.

The ULSAB vehicle FEM crash model (Figure 2) was developed by the Porsche Engineering Services, Inc. (PES) for the ULSAB Consortium.

Figure 2. ULSAB Vehicle Crash Model.

The crash model includes closure panels, drivetrain and additional masses necessary to simulate vehicle in-service conditions. Details of the crash model can be found in References 1 and 11.

FORMING SIMULATIONS

In order to investigate forming effects on crash performance, vehicle components that have the major influence on crash energy absorption have to be included in the forming analysis. Vehicle components that are designed to absorb crash energy during frontal crash are shown in Figure 3. The numbers in the figure denote vehicle part numbers as documented in the ULSAB report [1]

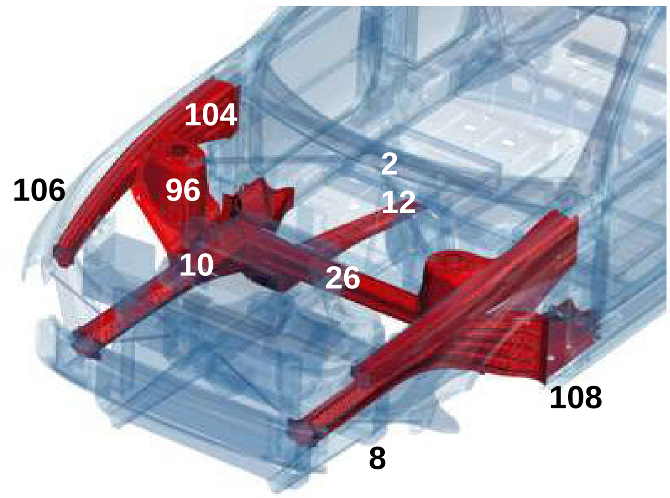

Figure 3. Main Frontal Crash Components.

The parts that were extracted from the crash model are shown in Figures 4-12.

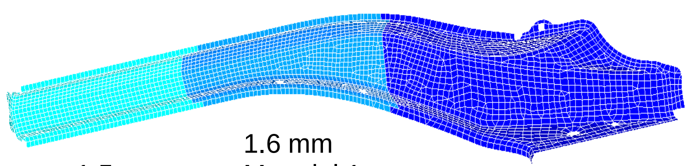

Figure 4. Part 10 – Front Rail Inner TWB.

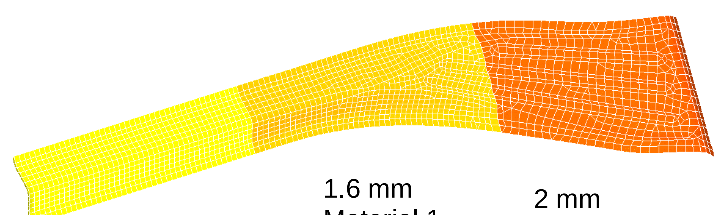

Figure 5. Part 8 – Front Rail Outer TWB.

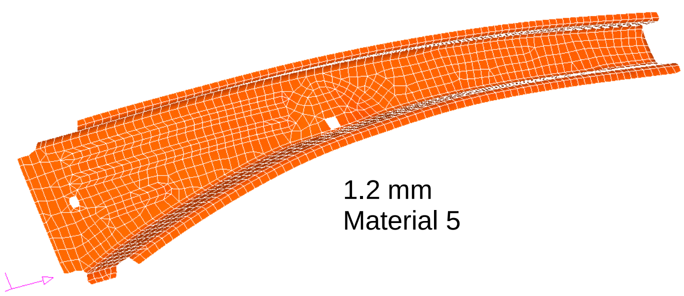

Figure 6. Part 104 – Rail Fender Support Inner.

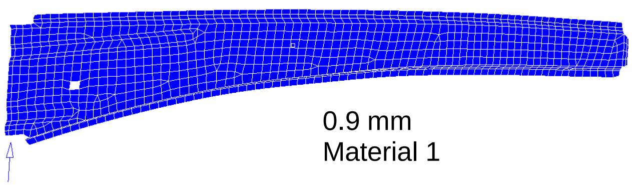

Figure 7. Part 104 – Rail Fender Support Inner.

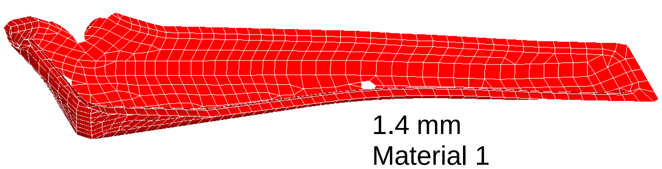

Figure 8. Part 12 – Rail Front Extension.

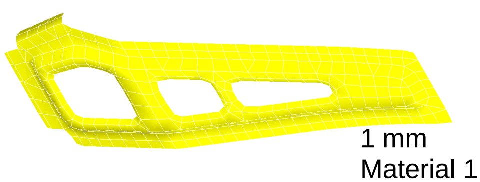

Figure 9. Part 2 Reinforcement Rail Front Extension.

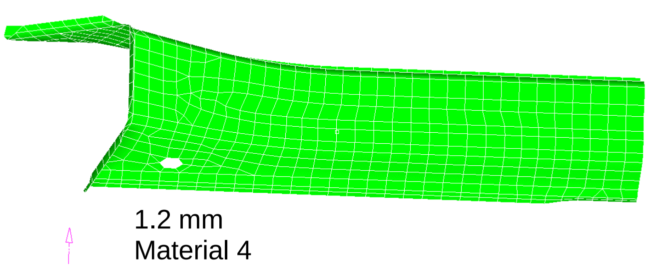

Figure 10. Part 26 - Member Dash Front (half).

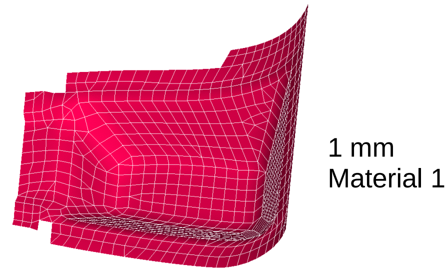

Figure 11.Part 108 – Reinforcement Front Rail.

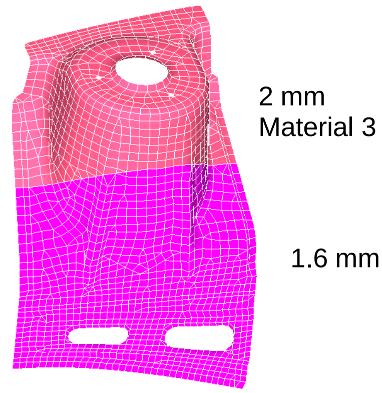

Figure 12.Part 96 - Panel Skirt TWB.

Several parts are made out of tailor welded blanks. TWB joints were modeled only through the change of thickness that occur at the connection. The effects of the welding on material properties have not been included. The material properties for the selected parts are shown in Figure13. The material data are based on quasi-static experiments and the corresponding true plastic strain-true plastic stress curves were used as parameters for the piece-wise-linear isotropic plasticity material model.

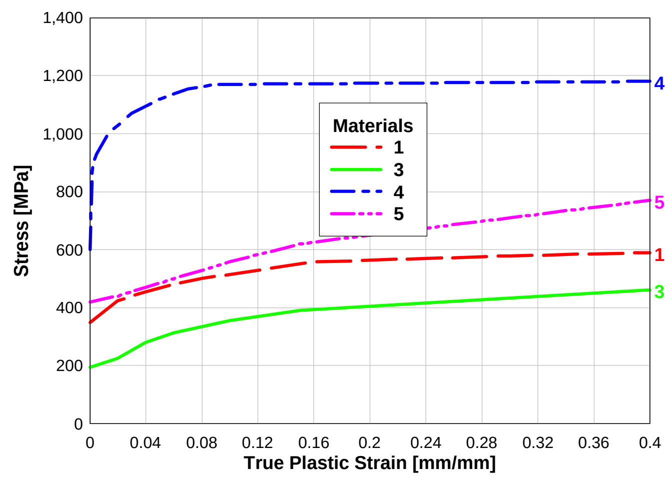

Figure 13. Material Properties.

Currently, there are several widely accepted FEM based formulations for modeling of sheet metal stamping [13, 14]. Detailed forming simulations require combination of sophisticated software and hardware [15]. New methods have also been proposed and have demonstrated promising results [16], but have not yet been used on complex industrial problems. Selection of stamping model formulation depends primarily on the intended purpose of the model. We wanted to select a formulation that can give reasonably detailed estimates for the overall conditions in the formed part while not requiring large effort for modeling all the details of the forming process. The One-Step Forming Method [17, 18] fits this overall objective while providing reasonable accuracy [19]. One-Step Method is commonly used in steel industry at the product design stage for quick evaluation of manufacturing feasibility without considerable investing into die design. The starting point of this approach is the FEM model of the stamped part. The problem is formulated in terms of mapping the position of the final part configuration into the starting blank. Because of the assumed linear displacement path between the starting and the final configurations, as well as for other simplifications, the method is considered to be a complementary tool for more general incremental displacement approach.

The refinement of the crash model in the frontal crash absorbing components allowed for using the same FEM discretization in stamping simulations and the complex mapping schemes are therefore serendipitously avoided. The density of the FEM discretization in the selected parts is similar to the discretizations reported in the literature [3] and within the restrictions placed by the One-Step forming approach. The intention was to produce large, yet still reasonable stretch in the parts so that the forming effects would be more likely to influence the crash behavior.

The forming analysis of certain component parts of the ULSAB vehicle was performed using the PC based computer program FAST_FORM3D [20] developed by Forming Technologies Inc. The car components analyzed have been extracted directly from the finite element model of ULSAB, the files were then converted to a NASTRAN format and fed to the analysis program as a pre-processed file with attached finite element mesh. The forming analysis was performed on a 'repaired' mesh that had all the holes and irregularities removed from the original mesh. For some cases sections of the part were modified to remove regions that presented 'undercut' which correspond to the non-unique linear mapping of formed shape into the blank. Material properties and component specific data were obtained from the finite element model of ULSAB. Material stress-strain data (Figure 13) were input directly to the program. The analysis was performed without the use of 'curve binders', which may have resulted in higher strains and stresses at the bends near the boundaries of the parts. Three components are formed using TWB option with individual blank thickness data for each region but with a common material for the entire blank.

The analyzed parts are characterized by a channel type configuration with small flanges along the major axis; the parts have gentle curvature along an axis normal to the part long axis and some curvature in the web of the channel. The analysis was performed using a draw-bead blank holding feature with a magnitude of 'draw-bead-strength' that was adjusted so that tearing of the part was inhibited. Calculated thickness associated with the forming process resulted in some regions where there was a minor increase in thickness attributed to the flowing of the material near the flange bends. These regions were limited in relation to the size of the blank.

The Table 1 shows the average plastic strain and thickness in the formed parts.

ULSAB Part. ID	Average Strain [%]	Average Thickness [mm]
8	4	1.8
10	12	1.5
26	3	1.18
2	4	0.97
12	22	1.19
96	16	1.6
108	13	0.93
104	19	1.04
106	4	0.87

Table 1. Averages of Forming Effects on Selected Parts

CRASHWORTHINESS SIMULATIONS

The forming strains and thickness variations for every finite element in the forming simulation were used for definition of part properties of the corresponding crash model parts. Certainly, there are other physical effects of forming process such as springback, residual stresses, damage, variations in Young's modulus, etc. In this study, they were considered to be secondary and were not included in the models. Crash scenario was frontal impact of ULSAB vehicle into flat rigid barrier with vehicle speed of 35 mph as specified in the U.S. Department of Transportation, New Vehicle Assessment Program (NCAP) test.

NCAP crash simulations for vehicle models with and without forming effects were performed using the massively parallel version of LS-DYNA3D [21]. Addition of forming effects into crash model does not have effect on computational time since it involves only the initialization of the problem. The results show that the dynamic of the deformation between the two cases is quite similar and does not reveal significant differences in collapse models for the considered parts. The side view of the deformed rails at 80ms into the crash is shown in Figures 14 and 15 for the two cases considered.

Figure 14. Front Rails – Coil Properties.

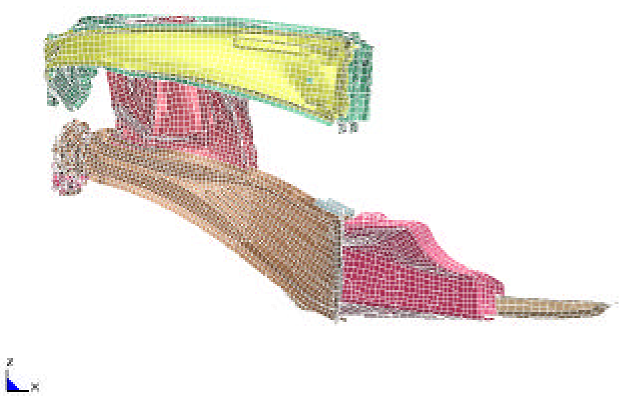

Figure 15. Front Rails – As-Formed Properties.

Lower rail is the main energy absorber in the frontal crash and its deformation for base and as-formed models are shown in Figures 16 and 17. As for the case of the entire rail system, the difference in the deformations is noticeable, however, not as important as for example for the case of strain rate dependent and strain rate independent material models [11].

Figure 16. Lower Rails – Coil Properties.

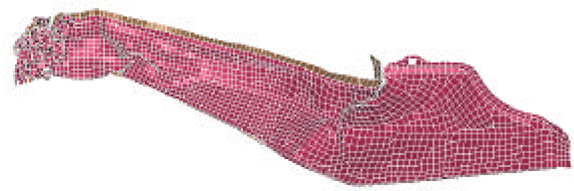

Figure 17. Lower Rails – As-Formed Properties.

Filtered (SAE J211) acceleration traces for the node at the rocker near the bottom of B-pillar are shown in Figure 18. This point on the vehicle is usually used as a link between occupant environment and the vehicle dynamics models.

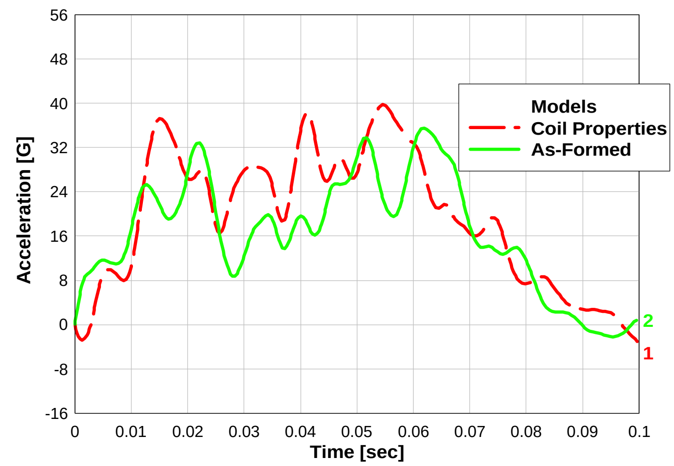

Figure 18. Acceleration at Rocker near B-pillar.

The average acceleration values are 19.4 G and 16.5 G for Coil and As-Formed cases, respectively. Average force in the lower rail is very similar for the two cases considered and even follows the same folding pattern as can be seen from oscillations in the force magnitude in Figure 19.

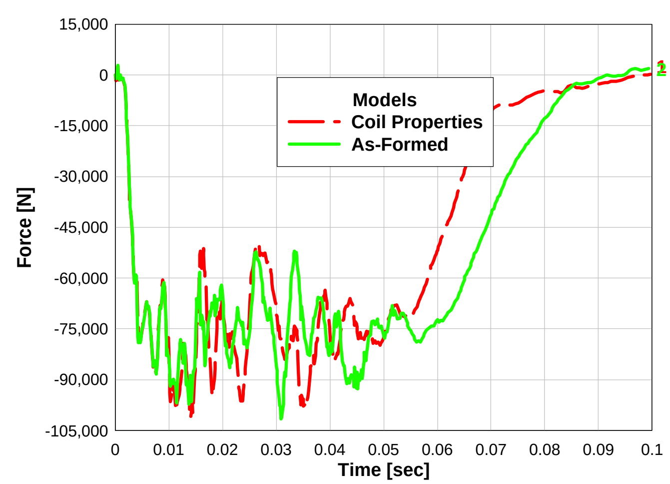

Figure 19. Force in Lower Rail.

The duration of the force is longer for the As-Formed case. The deformation of the rail is therefore 6% larger in the As-Formed case as can be seen in Figure 20. Curves in Figure 20 denote the distance between the centers of front and base cross sections of the rail.

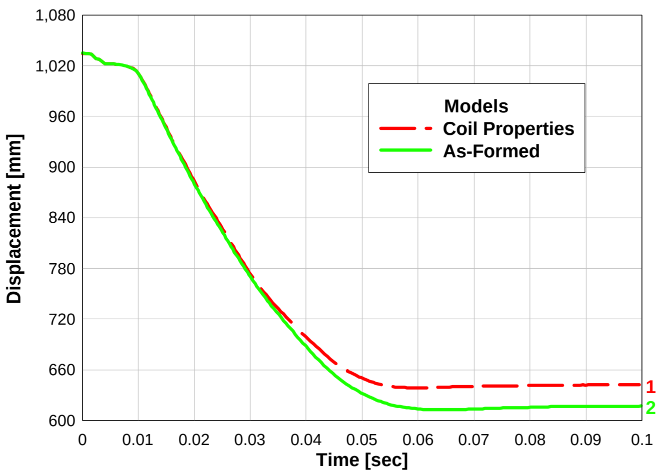

Figure 20. Lower Rail Length.

The fact that the forming results in larger deformation of the lower rail indicates that the forming thickness variations have larger effect than the plastic hardening. The stability of the sheet metal determines folding pattern and tendency to creation of localized hinges that dissipate crash energy. The last plastic hinge that is developing in the back of the crash zone in the rail is indeed more pronounced in Figure 17 than in Figure 16.

CONCLUSIONS

Crash modeling simulations show a moderate effect of forming on overall crash performance. The design is the determining factor on the vehicle performance and, therefore, the results of this research cannot provide measures that can be used in a general case. However, it has been shown that for materials that have modest strain hardening, the forming effect is observable and that when more complex forming operations are used, especially in combination with rapid strain hardening materials, forming effects should be taken in the consideration in the computational crash models.

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