"Forming to Crash" Simulation in Full Vehicle Models

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Keywords:
Forming, stamping,
finite element modelling, crashworthiness,
simulation, material

Abstract

Improving the accuracy of virtual prototypes helps to shorten product development times and reduces the number of physical prototypes required. One way in which the accuracy of crash analysis can be improved is to include the effects of forming in the material properties. Corus has developed a three-step "Forming to Crash" process to account for formed properties in crash analysis during both concept and detailed vehicle design stages. The first step uses a selection procedure to identify the parts most sensitive to the inclusion of formed properties. The second step uses an approximate "Forming to Crash" method to rapidly estimate the formed properties and reduce the time taken to conduct the analysis during concept design. The third step links a detailed forming analysis to a crash analysis to provide a full "Forming to Crash" technique for use during detailed design development. This three-step process is used by Corus to support customers in the application of advanced high strength steels.

Introduction

The process of forming a component changes the properties of the material being used. This is generally ignored in the design and validation process of automotive structures even though the changes in material strength and thickness may be substantial. Finite Element tools are now able to predict the as-formed material properties and use these in subsequent crash analysis. However, although the forming effects on the performance of individual components have been reported in the literature [1][2][3][4][5][6][7][8], there are few papers reporting the consequence of including formed properties in full vehicle models [9][10]. This paper presents Corus developed procedures, which are used to include the results of forming simulations in the full vehicle crash model.

Corus "Forming to Crash" Three-Step Process

A vehicle body structure consists of hundreds of formed components. A detailed analysis of the stamping process can take between 5 to 10 days per part to complete. In order to minimise the time taken for vehicle analysis, it is therefore important to understand which components in the vehicle body structure are sensitive to forming and how the formed properties affect the vehicle crash performance. The identification of the key parts in which to include formed properties is the first stage of a "Forming to Crash" (F2C) three-step process, which has been developed by Corus.

Step 1: Select the parts sensitive to "Forming to Crash"

In this step the parts for which it is important to include formed properties in the crash analysis are identified.

Step 2: Approximate "Forming to Crash" analysis

In this step the formed properties are estimated in the crash analysis. This makes it possible to rapidly assess the crash performance sensitivity of the structure to the inclusion of formed properties.

Step 3: Full "Forming to Crash" analysis

In the final step, the formed properties are predicted using a full forming analysis and are mapped into the crash analysis model. This provides a detailed prediction of the strength levels and thickness of the material throughout the part, which are used as inputs to the subsequent crash analysis.

This “Forming to Crash” (F2C) procedure is used by Corus to support customers to account for formed properties when using Corus material in crash structure applications. The approximate F2C technique is used predominantly in the concept stage of vehicle design, with the full F2C technique being used during detailed structural design. Both of these techniques will be presented in more detail later in the paper. Before this, however, it is appropriate to consider factors which influence the “Forming to Crash” behaviour of structures.

Factors Influencing “Forming to Crash” Behaviour

There are three key factors which will influence the behaviour of crash structures when considering “Forming to Crash”; material strength change, material thickness change and final geometric shape.

The material strength and thickness change results from straining of the material during the forming process. Figure 1 shows the stress-strain curve of a material with a yield strength of approximately 220MPa. Forming introduces a residual strain in the material. This hardens the material, giving an effective increase in yield strength for subsequent deformation. As may be seen in Figure 1, a 5% forming strain increases the yield strength by more than 70MPa.

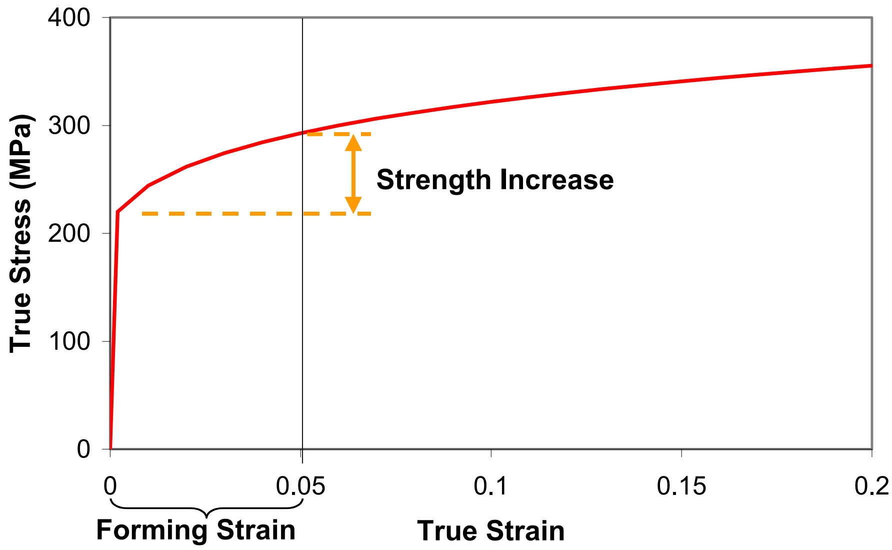

Figure 1 Material Strength Characteristics

The change in material thickness after forming is illustrated in Figure 2, where the thickness has decreased by up to 12% from the starting material thickness of 1.6mm.

The final geometric shape refers to the shape after forming, which can differ from the design intent. This is influenced by the elastic recovery of the material and is especially an issue for high strength steels. This is illustrated in Figure 3, which compares two top-hat section boxes formed by the same deep drawing process. The box made from Dual Phase material has non-parallel sidewalls (sidewall curl) and a curved top (spring-back). This is a consequence of the high yield strength of the Dual Phase material and the residual stresses and strains introduced into the material during forming. This shape has the potential to influence the collapse initiation of the section.

The influence of these three factors on box section collapse is illustrated in Figure 4, which shows the results from dynamic crush tests on two double top-hat section boxes, impacted under the same conditions but formed in two different ways [11]. It is clear that the forming process has significantly influenced crash performance, and this trend was observed consistently in all tests undertaken.

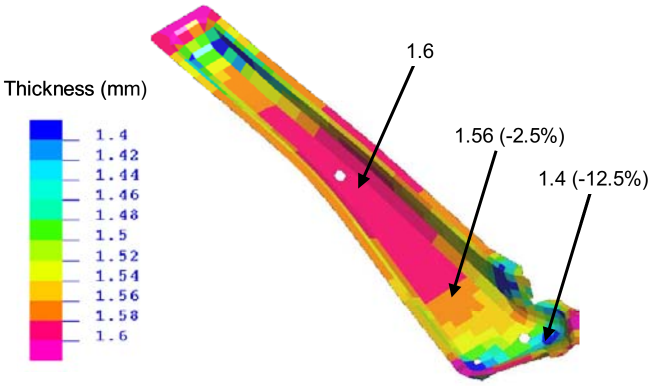

Figure 2 Material Thickness Change After Stamping

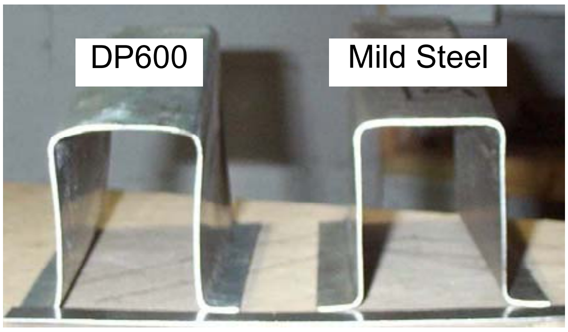

Figure 3 Component Shape After Forming

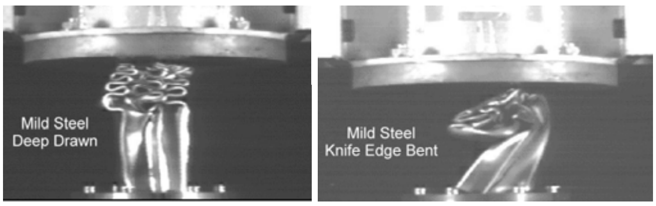

Figure 4 Forming Influencing Crash Performance

A "Forming to Crash" Case Study

A modified version of the ULSAB [12] crash model was analysed in LS-DYNA with and without formed properties included in some of the main impact members to illustrate the significance of "Forming to Crash" in full vehicle structures. Figure 5 shows the difference in collapse mode of the lower longitudinal for the standard crash analysis (not including formed properties) and the "Forming to Crash" analysis with formed properties included. In this case study the thickness change and plastic strains were included for the lower longitudinal (sub-frame extension) only, which is circled in Figure 5. The figure clearly shows that the mode of deformation of the lower longitudinal improved significantly when formed properties were included. However, making the front structure stronger by including the formed properties resulted in higher forces being passed back into the support structure. This increased the level of deformation in this area of the structure.

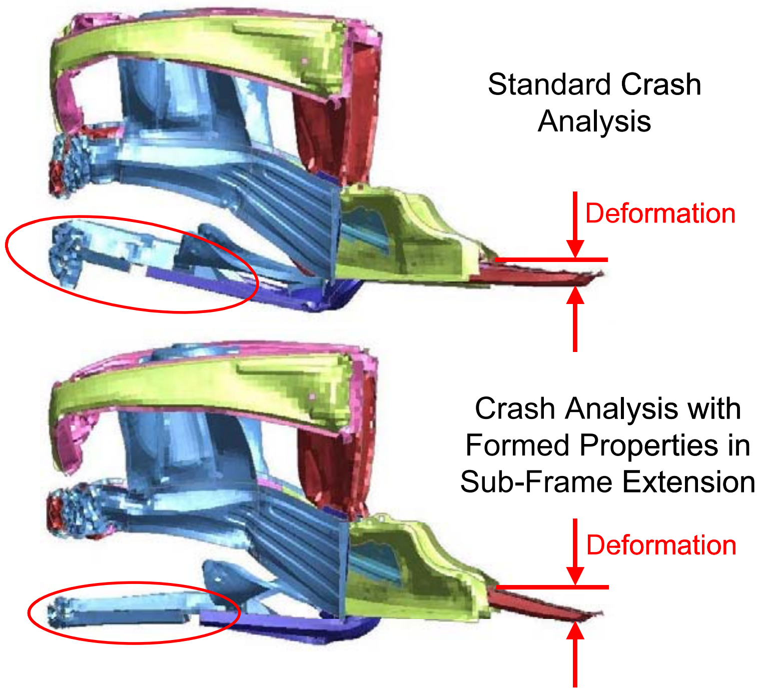

Figure 5 Differences in Crash Performance Due to Forming in Full Vehicle Model

Generally, the influence on the overall crash performance of the vehicle was small. The main differences observed were in the modes of deformation of individual components and in the distribution of the internal energy in the parts at the front of the vehicle. The energy absorbed by some of the small parts, mainly reinforcements inside the longitudinal and under the dash, changed by up to 40%.

The important conclusion from this study is that including formed properties in the main impact members will not only influence the performance of those parts but can also have a significant influence on the loading and deformation modes of the surrounding components. This is why Corus has developed the three-step "Forming to Crash" process, which enables "Forming to Crash" to be undertaken at both the concept stage and detailed stage of vehicle design.

Approximate "Forming to Crash"

At the vehicle concept stage, the architecture of the structure is built around the packaging information. This is a very important and dynamic phase of vehicle design, since only package and approximate skin surfaces are fixed. At this stage it is possible, with an appropriate "Forming to Crash" process, to design members to include the effects of "Forming to Crash". It is important to be able to estimate the level of change in performance from material changes introduced by the manufacturing process.

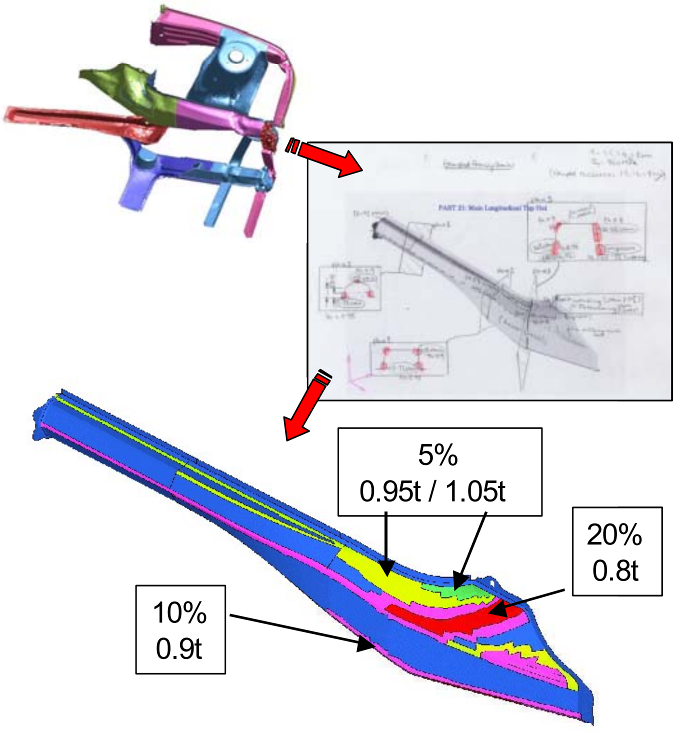

Figure 6 Estimated Zones of Forming Strain

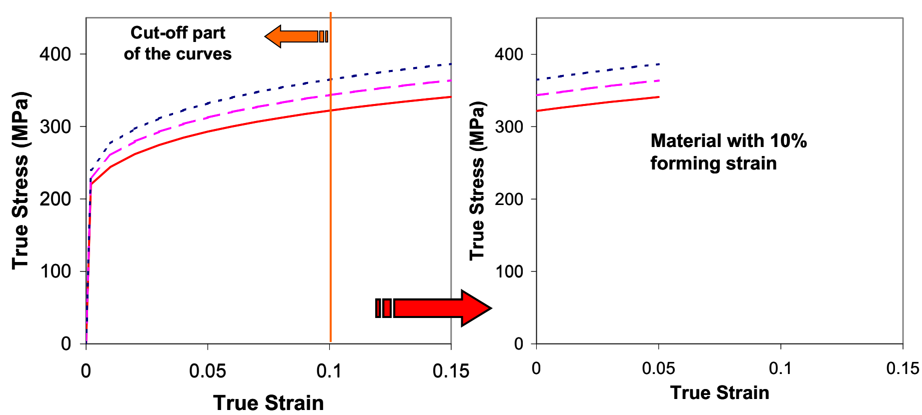

Figure 7 Left-Shift of Material Strain Rate Curves

The basis of the Corus approximate "Forming to Crash" technique is to use material and forming expertise to estimate the levels of strain in a component based on the material and forming process to be used. This is illustrated in Figure 6, where a sketch of the part is marked-up by material and forming specialists with estimated levels of equivalent plastic forming strain. By assuming a balanced bi-axial strain state the thickness is easily estimated, since the change in thickness is approximately proportional to the equivalent plastic strain. Therefore a 10% strain is assumed to give a 10% change in thickness.

The influence of forming strains on the strength of the material is included in the crash material models by using the approximate equivalent plastic strains to left shift the material stress-strain curves. This technique is illustrated in Figure 7, which shows the modification of material curves at various strain rates for a 10% forming strain. Although Figure 7 shows the modified material with only a 5% elongation, in practice Corus extends the modelled material curves. This is done based on Corus knowledge of the stress-strain relationship of the material grade between the strain at tensile strength and the strain to fracture (i.e. necking of the material).

The use of these modified material properties in finite element (FE) crash analysis, requires the creation of some additional parts in the FE input deck, with (left-shifted) material curves and formed thickness corresponding to the different zones of strain.

Full "Forming to Crash"

At the detailed vehicle development stage, it is important to have accurate virtual prototypes for crash and durability predictions. Including formed properties in appropriate areas of the structure can improve correlation with test. At this stage of the design process the geometry of the structure changes less frequently compared with the concept design stage and therefore there is more time to undertake detailed forming simulations and use the predicted formed properties in crash analysis. Corus refers to this as the Full "Forming to Crash" process.

Corus uses PAM-STAMP to perform forming simulations and the PAM suite includes a mapping feature for linking PAM-STAMP to PAM-CRASH. However, Corus has also developed procedures for mapping the results from PAM-STAMP to LS-DYNA and RADIOSS.

The full "Forming to Crash" technique takes significantly more time to complete compared to the approximate "Forming to Crash" technique due to the extended time required for a full forming simulation. This is why this technique is only used during detailed design development.

Comparison of Approximate and Full "Forming to Crash"

The modified version of the ULSAB crash model was used to run the approximate and full F2C simulations. This enabled a comparison to be made between the results of the two techniques.

Figure 8 shows the comparison between the estimated and the full forming predicted strains of the main longitudinal inner. Although at first sight there may seem to be poor correlation between the two strain distributions, further examination reveals that the strains are reasonably close considering the very approximate nature of the estimation.

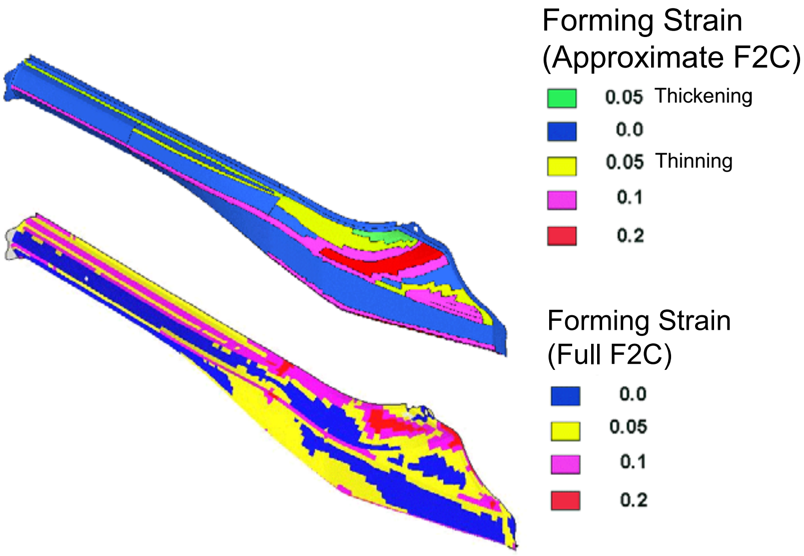

Figure 8 Forming Strain Comparison

Figure 9 compares the difference between the predicted energy absorption of individual parts in the modified version of the ULSAB model using the approximate and full F2C analyses. The absolute difference (the wider bars) is less than 0.6 kJ and the percentage difference (the narrow bars) is within 20%. For the concept stage of vehicle design, the 20% margin for the approximate F2C technique is acceptable.

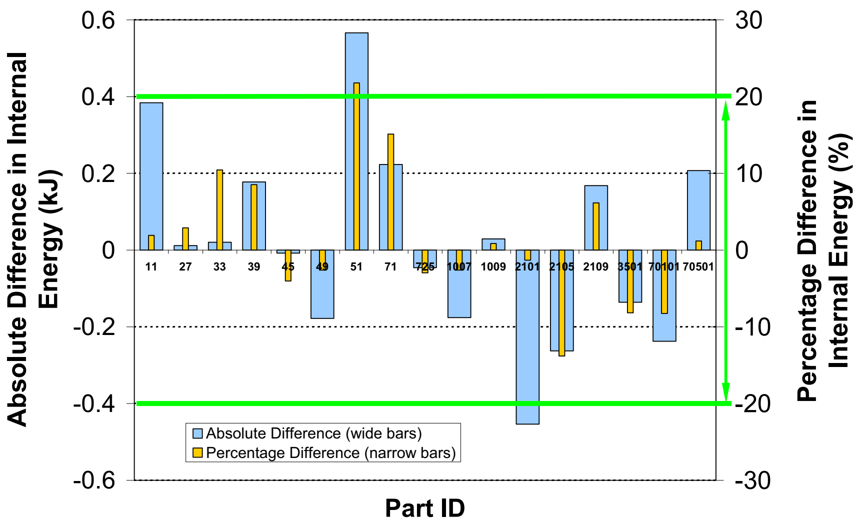

Figure 9 Comparisons of Internal Energies in Individual Parts for Approximate and Full F2C Analyses

The approximate F2C technique has, therefore, been shown to provide good correlation with the full F2C technique, with the advantage of being very fast to implement. However, the success of this approximate technique relies very much on the experience of the material and forming specialists providing the estimations.

Selection Procedure

As discussed earlier, the Corus "Forming to Crash" three-step process starts with the identification of parts in which it is important to include formed properties in the crash analysis. This is to limit the number of parts which need to be subjected to a F2C analysis, and in so doing minimise analysis time.

Corus has developed a selection tool, which is used by material and crash experts, to help select the parts. The selection procedure has been developed for use with frontal impact load cases and the ranking process is based on a number of assumptions and simple calculations. The tool has five built-in scenarios to compare sensitivity to such parameters as peak force and energy absorption.

This tool was used to select the parts requiring F2C analysis for the modified version of the ULSAB structure referred to earlier in the paper.

Summary and Conclusions

Including formed properties in vehicle body structure can have a considerable influence on collapse modes of these components and, importantly, a significant influence on the energy absorbed by surrounding components.

The Corus "Forming to Crash" three-step process enables time-efficient inclusion of formed properties in crash analysis during both the concept and detailed design stage. The process uses a selection procedure, in combination with expertise in materials and forming, to provide rapid assessment of the sensitivity of a structure to formed properties. Detailed design is then supported through the use of full forming simulation linked to the major crash analysis codes.

"Forming to Crash" has now become a feasible design analysis process and is one of a range of advanced material modelling techniques developed by Corus to support customers in the application of advanced high strength steels.

Acknowledgements

The authors would like to express their thanks to Professor Jon King, Director, Corus Automotive and Mr. Kevin Draper, Manager Applications and Service Development, Corus Strip Products IJmuiden for their permission to publish this paper. The authors also wish to thank their colleagues within Corus for their support and assistance.

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