Modeling Forming Effects for Crash Simulation: Recent Advances in HYCRASH

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Abstract

Modeling the effects of plastic forming on thin metal components is essential for accurate crash performance predictions in automotive simulations. HYCRASH, a fast one-step solver that estimates strain and thickness distributions from product geometry, has been continuously enhanced to improve crash simulation accuracy and streamline modeling workflows. Recent crash simulations demand the handling of large-scale vehicle models, diverse component geometries, and complex physical phenomena such as fracture. Addressing these challenges is critical to advancing simulation-driven vehicle design.

This paper presents the latest developments in HYCRASH, including the consideration of the Bauschinger effect, support for pipe-shaped components, and the transfer of damage values between forming and crash analyses. In addition, efforts to accelerate the solver and enhance usability through a more efficient modeling environment are described. These advancements improve both the accuracy and practicality of incorporating forming effects into crashworthiness analysis. The ongoing development of HYCRASH contributes to more reliable crash simulations and greater efficiency in automotive design processes.

1 Introduction

In crash simulations of automobiles, modeling that accounts for the forming history of thin metal components is a crucial factor influencing the accuracy of energy absorption prediction. To obtain the thickness reduction and initial strain distribution caused by plastic forming, it is usually necessary to perform a sequential analysis that reproduces the forming process [1]. However, such forming analyses require detailed definitions of die geometry and forming conditions, which results in significant preparation effort and computational time, posing a challenge in practical applications.

HYCRASH is a one-step solver that identifies thickness reduction and initial strain distribution directly from the final geometry of a formed part [2]. Without requiring die geometry or detailed forming conditions, it enables the rapid modeling of forming effects. Owing to its efficiency and high practicality compared with conventional methods, this approach has been widely used in automotive crash simulations [3].

In recent years, the automotive industry has been under increasing pressure to shorten development periods and establish more efficient design methodologies in order to strengthen global competitiveness. To minimize design rework, higher accuracy in simulation is required. At the same time, faster modeling, computation, and post-processing are essential to shorten development cycles. Furthermore, with the growing shortage of skilled engineers, software usability has become indispensable for establishing development processes that do not rely on individual expertise.

In this context, HYCRASH has been continuously enhanced in terms of accuracy, speed, and usability, with the aim of contributing to more efficient automotive development. In this paper, the key features of HYCRASH are first outlined. Subsequently, recent developments aimed at improving accuracy are introduced, including the incorporation of material models considering kinematic hardening, the transfer of damage values generated during forming, and the extension to closed-section geometries such as pipes. Furthermore, efforts to improve computational speed and usability are described. Through these developments, modeling methodologies for efficient crash performance evaluation using HYCRASH are proposed.

2 Overview and Features of HYCRASH

This section presents an overview and functional characteristics of HYCRASH. HYCRASH employs a unique algorithm based on the minimization of deformation energy required to transform a blank into the final product shape. As a result, it can perform stable and highly accurate computations even for complex product geometries.

In practical plastic forming, various forming methods are selected depending on formability considerations, and each method produces characteristic strain and thickness reduction. For example, when a blank is constrained by a blank holder to suppress wrinkling, the sidewall region accumulates strain due to unbending and stretching.
HYCRASH allows the user to select among three representative forming methods: BEND (bending), FORM (general forming), and DRAW (deep drawing). Calculation examples for these representative forming methods are shown in Fig.1. This functionality enables the consideration of forming-method-dependent deformation, which cannot be directly inferred from geometry alone, and reflects strain distributions characteristic of each forming process.

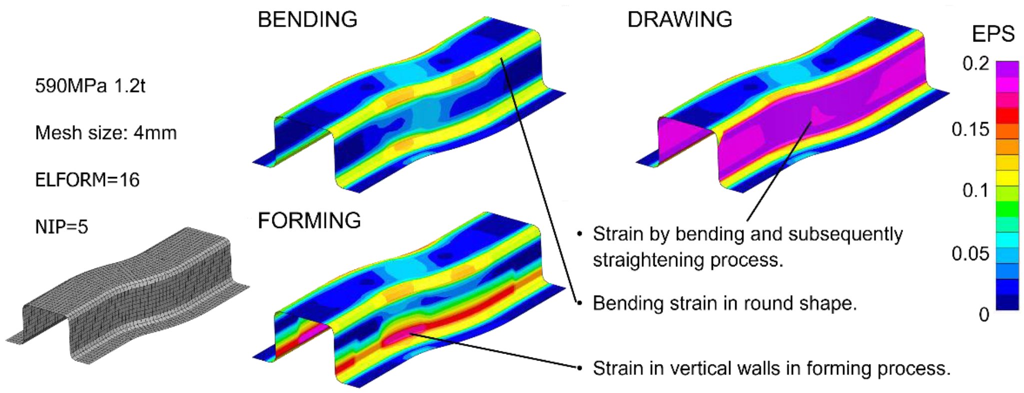


Fig.1: Calculation example examples of representative forming methods (BEND, FORM, DRAW) available in HYCRASH.

Furthermore, the final thickness and strain distributions obtained for each component must be incorporated into a full-vehicle crash model. HYCRASH directly accepts the full-car model as input and outputs results while preserving boundary and initial conditions. The overall process flow of HYCRASH is illustrated in Fig.2. This seamless workflow eliminates the need for additional data transfer or model conversion by the analyst.

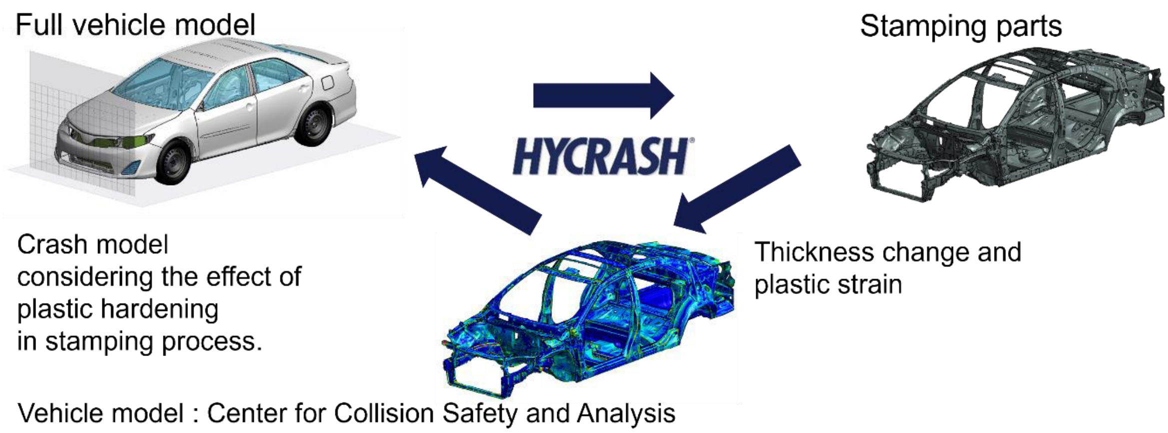


Fig.2: Process flow of HYCRASH from input to output.

3 Enhancements for Improved Accuracy

This chapter describes the newly implemented functionalities in HYCRASH aimed at improving predictive accuracy. Three features are addressed: consideration of back stress based on a kinematic hardening law, transfer of the damage variable, and modeling of closed-section forming processes. The details and effects of each are presented in the following sections.

3.1 Consideration of Back Stress Based on Kinematic Hardening

In metallic materials, when subjected to repeated large deformations, early re-yielding after stress reversal occurs, followed by a change in the subsequent work hardening rate, which is known as the transient behavior of Bauschinger effect. In addition, a permanent softening phenomenon characterized by a reduction in flow stress is also observed [4]. An outline of these effects is shown in Fig.3.
During plastic forming, materials may undergo reverse deformation such as bending and unbending, and modeling of the Bauschinger effect has a significant influence on the accuracy of shape prediction after forming. Similarly, in crash analyses, deformation in the direction opposite to that imposed during forming is often assumed. In such cases, modeling of the Bauschinger effect may also affect the prediction of reaction forces and energy absorption during deformation.

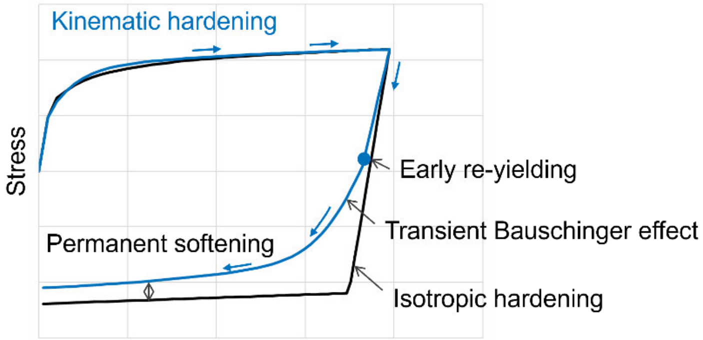


Fig.3: Schematic illustration of the transient Behavior of Bauschinger effect and permanent softening.

Fig.4 presents a schematic of isotropic hardening and combined hardening with back stress, along with the corresponding material model numbers in Ansys LS-DYNA. In HYCRASH, in addition to strains obtained during the forming process, a feature has been implemented to transfer back stress as a history variable in these material models. This makes it possible to readily conduct crash simulations that consider the Bauschinger effect.

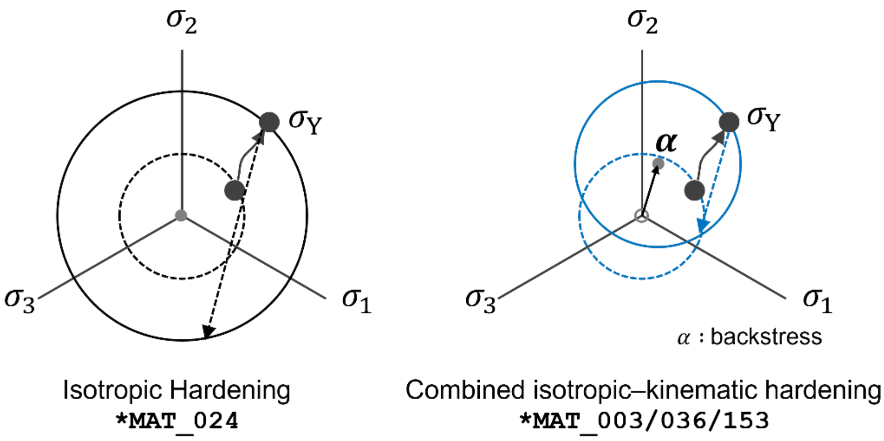


Fig.4: Schematic of isotropic hardening and combined hardening with back stress (with corresponding material model numbers in Ansys LS-DYNA).

Fig.5 illustrates the reaction force and energy absorption in a three-point bending analysis of a hat-shaped component made of 590MPa-grade steel, in which the initial conditions were defined by the strain and thickness distributions identified by HYCRASH, while the back stress induced during forming was also transferred. Compared with the isotropic hardening model, the case considering back stress exhibits a reduction in reaction force by approximately 10–18% and a decrease in energy absorption by about 10%. Furthermore, as shown in Fig.6, the equivalent plastic strain distribution at the final deformation using the combined hardening model indicates that the corner region of the hat-shaped component deforms in the direction opposite to the bending imposed during forming. This suggests that the reduction in reaction force and energy absorption is attributable to a decrease in deformation resistance caused by the Bauschinger effect.

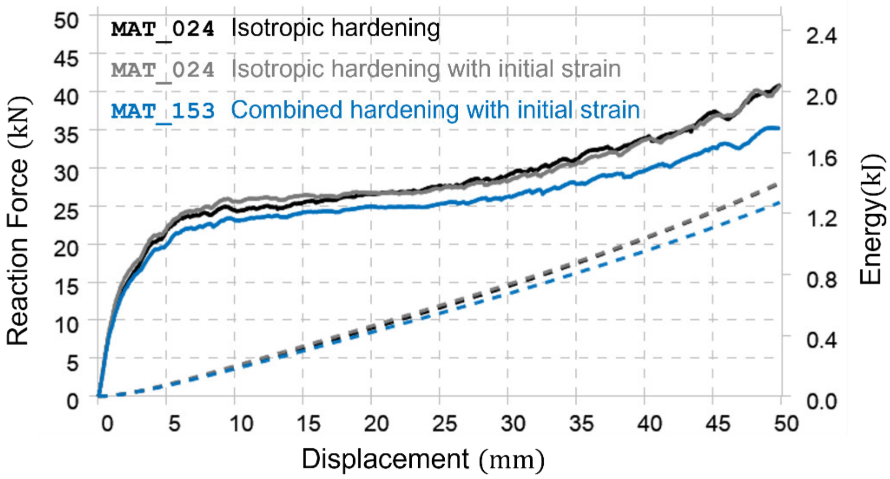


Fig.5: Reaction force and energy absorption in a three-point bending analysis of a hat-shaped component made of 590MPa-grade steel. Solid lines represent reaction force, while dashed lines represent energy absorption.

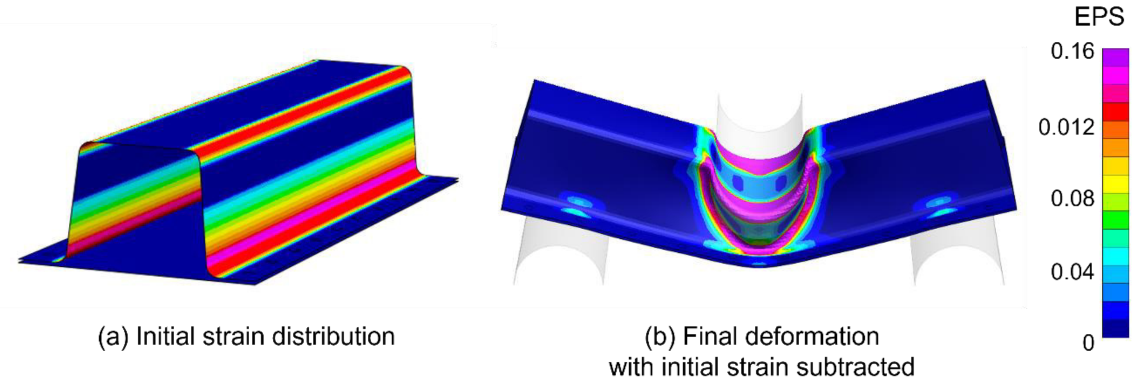


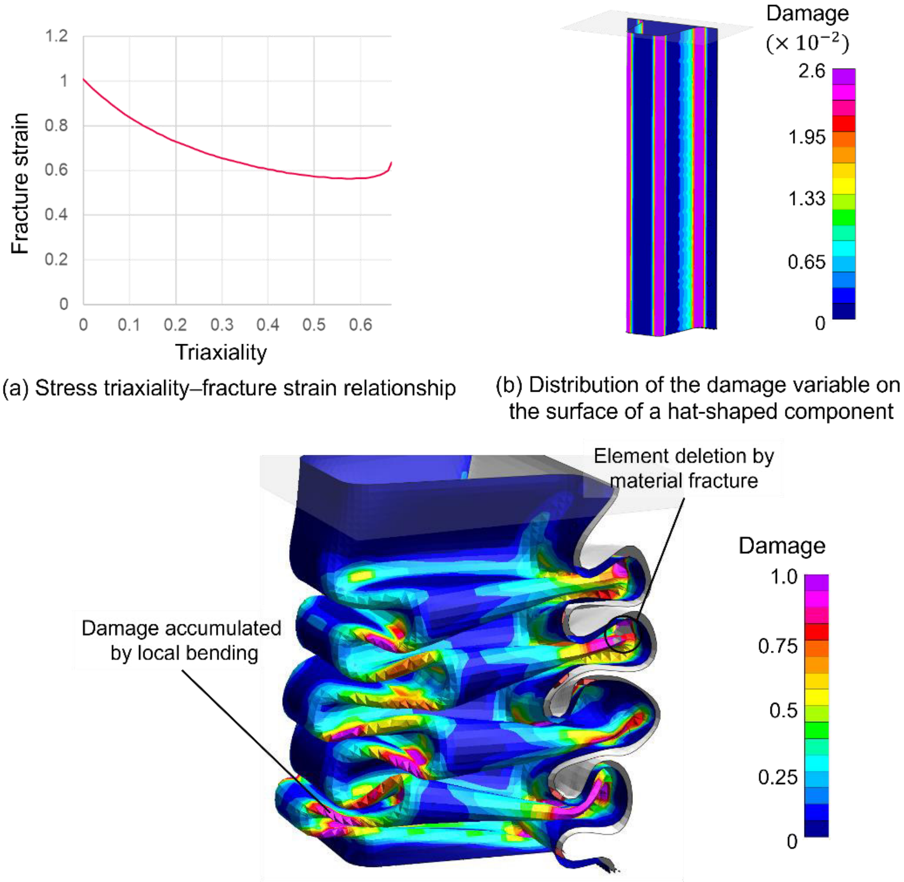
Fig.6: Equivalent plastic strain distribution at the initial condition and final deformation in a three-point bending analysis of a hat-shaped component using the combined hardening model.

3.2 Transfer of Damage Variable

In recent years, the trend toward vehicle weight reduction has driven the development of high-strength metallic materials. As a result, highly accurate fracture prediction for structural components made of thin sheets has become increasingly important. To Adress this requirement, the accumulative damage model GISSMO (Generalized Incrementa Stress-State dependen Damage MOdel) has been developed, and its capability for accurate fracture prediction has been validated [5,6]. The model is now widely implemented in Ansys LS-DYNA.

In HYCRASH, a new functionality has been developed to estimate the GISSMO damage variable accumulated during the forming process. This functionality refers to the stress triaxiality–fracture strain relationship defined for each material and evaluates the damage variable based on the parameters controlling its accumulation. Furthermore, by outputting the estimated damage variable together with the initial strain as history variables of the material model, HYCRASH provides a process-coupled approach for fracture prediction modeling.

Fig.7 shows stress triaxiality–fracture strain relationship for a 590 MPa material, distribution of the damage variable on the surface of a hat-shaped component estimated by HYCRASH, and the corresponding crushing result. Due to local bending deformation induced by buckling, damage variables indicating fracture are observed on the tensile surface. In addition, for elements in which multiple layers across the sheet thickness have fractured, element deletion due to rupture is observed.



(a) Stress triaxiality–fracture strain relationship

(b) Distribution of the damage variable on the surface of a hat-shaped component

(c) Crushing result

Fig.7: Damage analysis results for a 590 MPa material estimated by HYCRASH.

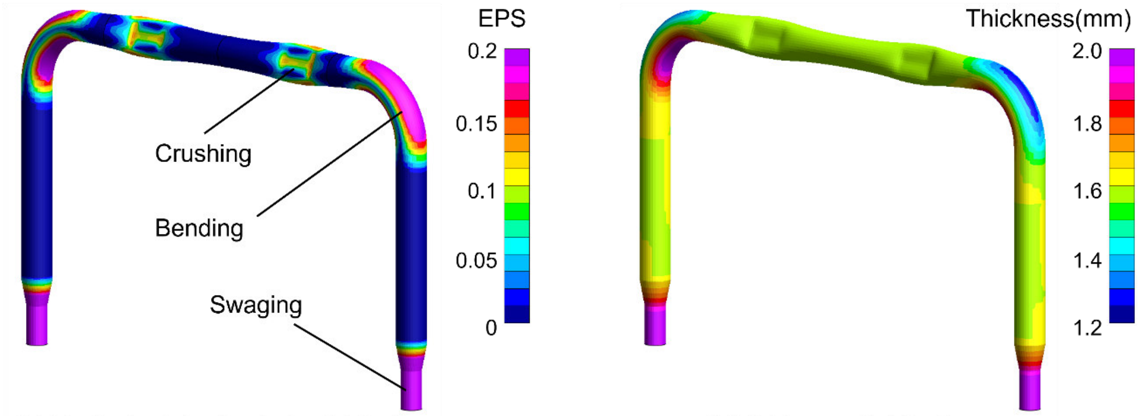
3.3 Modeling of Closed-Section Forming Processes

For components with closed cross-sections, such as pipes, HYCRASH has been extended to represent both the forming process from a flat sheet into a closed section and various subsequent cross-sectional forming operations. The implemented functionalities are summarized below.

ROLL simulates the forming of a closed section by rolling a flat sheet into a circular cross-section, during which bending strains are calculated, while strains induced by welding are not considered. PBEND calculates strains associated with bending operations based on the curvature of the pipe's central axis and its radius. RESIZE accounts for diameter expansion or reduction, estimating strains from changes in circumference that induce thickness variation and changes in axial length. SWAGING represents expansion or reduction at pipe ends, calculating strains associated with smoothly varying geometrical transitions. Changes in axial length are also considered. CRUSH simulates crushing processes, in which a circular cross-section is flattened by dies or similar tooling, and estimates the resulting strain distribution.

In PBEND and CRUSH, a dedicated algorithm is applied to identify the central axis of the pipe and to evaluate geometric changes induced by forming. In addition, combined operations can be specified, such as PBEND with SWAGING or PBEND with RESIZE.

Fig.8 shows the strain and thickness distributions in a pipe component with an outer diameter of 25.4mm and wall thickness of 1.6mm, subjected to bending, swaging, and crushing operations. It can be observed that characteristic strain patterns and thickness variations associated with each forming process are successfully reproduced.



(a) Equivalent plastic strain distribution (b) Thickness distribution

Fig.8: Estimation of equivalent plastic strain and thickness distrubution in a pipe component subjected to forming process HYCRASH.

4 Computational Speed

The cost associated with modeling and computation is a critical factor influencing the efficiency of the design process. In HYCRASH, the initial material conditions of a full-vehicle crash model are directly modeled at the time of crash analysis input; therefore, reducing turnaround time has always been an important challenge.

In the next version of HYCRASH ver2.6B, currently under development, the preprocessing algorithm has been redesigned to improve efficiency. Furthermore, parallel computation has been introduced in the one-step solution procedure, enabling significant reductions in computation time, particularly for large-scale components.

The computation time required to model initial strain and thickness distribution with HYCRASH was evaluated for an full-vehicle model consisting of 27 million elements. In this case, HYCRASH was applied to 392 parts with a total of 5 million elements. The computation time comparison is summarized in Table 1. With the improved preprocessing algorithm and support for multi-core environments, the computation time was reduced by approximately 60% compared with the previous version.

Whole model	**Targeted by HYCRASH**		**Computation time(min)**	
Number of elements	Number of parts	Number of elements	Previous version with a single core	Latest version with 4 cores
27 million	392	5 million	247	95

Table 1: Comparison of computation times with HYCRASH for the full vehicle model

5 Usability

In HYCRASH, the selection of forming methods and specification of various options must be defined in the header section of the Ansys LS-DYNA input file; for this purpose, a dedicated configuration tool is provided. This tool operates on PRIMER, a pre-processor developed by ARUP, and enables smooth operation even for large-scale models. Once the configuration is completed, HYCRASH can be executed directly from the tool. Moreover, after the computation, the results can be automatically applied to the original model while preserving its include-file structure.

Fig.9 illustraites the user interface of the configuration tool together with a schematic diagram of the data flow. With this tool, efficient and straightforward modeling can be achieved even for models involving a large number of parts and requiring complex settings.

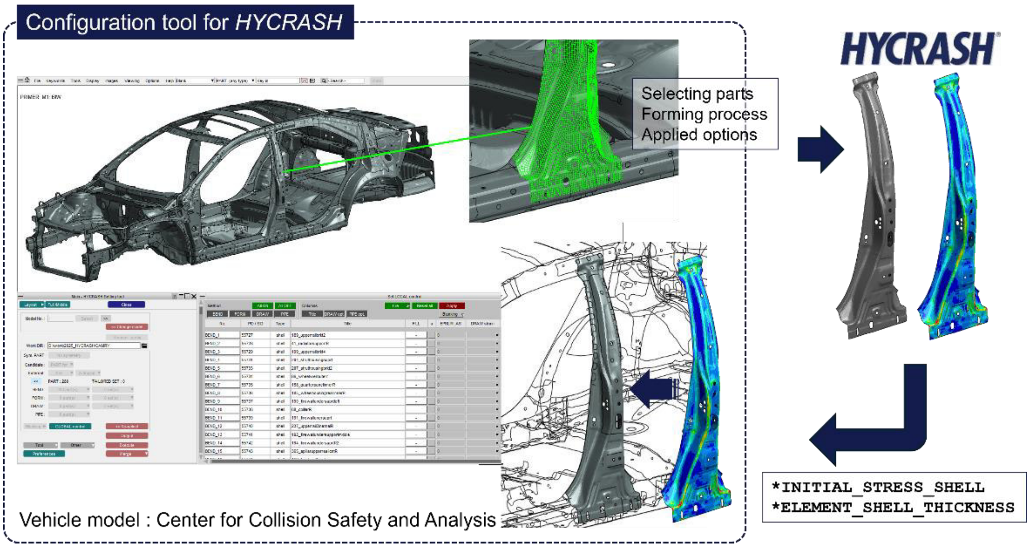


Fig.9: User interface of the dedicated configuration tool for HYCRASH and schematic deagram of the data flow.

6 Operational Proposal and Future Development

When representing the effects of sheet metal forming through the definition of thickness and initial strains, Ansys LS-DYNA uses the element definition (***ELEMENT_SHELL_THICKNESS**) and the initial stress definition (***INITIAL_STRESS_SHELL**). With the increasing scale of recent full-vehicle models, the size of the initial strain data can become extremely large. Moreover, during the design phase, where parts are frequently replaced, the handling of such data becomes cumbersome. Accurate processing requires expertise and imposes a substantial burden on engineers.

In the operation of HYCRASH, the use of a dedicated configuration tool enables straightforward reconfiguration and recalculation of replaced parts, allowing the model to be updated without manually adjusting the include-file structure. In HYCRASH, forming methods and various options are specified in the header section of the Ansys LS-DYNA input deck, and calculations are performed by referencing material and thickness information defined in the input file. After the computation, the results are output as the original crash model, with initial velocity and boundary conditions preserved. Furthermore, by sending the model with updated header information to the server and executing HYCRASH as a preprocessing step prior to crash analysis, the modeling workload for engineers can be significantly reduced.

On the other hand, because a full-vehicle model consists of a large number of parts, selecting the appropriate forming method can be time-consuming. In addition, in crash analysis departments, it is often difficult to obtain sufficient information to determine the forming method for each part. To address this issue, we plan to develop a server-based technology that automatically identifies and selects forming methods based on component geometry.

Ultimately, the goal is to establish an environment in which engineers can perform modeling without being consciously concerned about the effects of sheet metal forming, thereby supporting efficient and high-accuracy design processes.

7 Summary

This study addressed the challenge of incorporating forming history in automotive crash simulations by proposing an approach based on the one-step solver HYCRASH, and demonstrated its features and effectiveness. HYCRASH does not require conventional sequential forming analyses; instead, it directly estimates thickness reduction and initial strain from the final geometry, thereby offering high practicality within the design process.

In addition, newly implemented functions, such as the consideration of back stress, transfer of damage values, and modelling of closed-section components, enabled more accurate representation of forming

history. Furthermore, improvements in preprocessing algorithms and the introduction of parallel computation significantly reduced computation time, even for large-scale models.
A dedicated configuration tool operating on PRIMER was also developed, providing an efficient and intuitive environment for handling large and complex models. This allows forming history to be considered even by designers and analysts without specialized expertise, thereby enhancing the applicability of the method in practice.
Overall, HYCRASH demonstrated superiority over conventional methods in terms of accuracy, computational efficiency, and usability, contributing to the construction of a practical crash analysis process. Moving forward, through further algorithmic extensions and operational improvements, HYCRASH is expected to make an even greater contribution to improving design efficiency in automotive development.

8 Literature

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