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Integrated CAE framework from manufacturing processes to performance prediction

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To enhance the prediction accuracy of CAE simulation results for vehicle performance, this study develops an integrated CAE framework that consistently transfers manufacturing-induced physical state changes from manufacturing processes to performance evaluation. Although performance CAE is widely used to support design decisions, discrepancies between CAE predictions and experimental results are still observed in practice. One major cause of such discrepancies is the difficulty in consistently accounting for physical state changes generated during manufacturing processes. In conventional workflows, performance CAE models are often based on nominal geometry, while manufacturing-induced deformation, thickness, plastic strain, and stress states including residual stress are neglected or only partially considered. Although previous studies have proposed limited transfer of manufacturing information, consistent handling of multiple physical states across an entire manufacturing process chain remains challenging.

The objective of this study is to enhance the prediction accuracy of performance CAE results by appropriately reflecting manufacturing-induced changes in physical states., specifically geometry, thickness, plastic strain, and stress states including residual stress, into performance analysis. To achieve this objective, an integrated CAE framework covering press forming, welding, and drying processes was constructed, enabling the consistent inheritance of physical states up to performance CAE. In the proposed framework, geometry information is transferred using mesh data, while thickness, plastic strain, and stress information are inherited as scalar or tensor quantities according to their characteristics. Material properties are also handled consistently by transferring material parameters between CAE solvers, allowing coherent tracking of physical states throughout the process chain. Figure 1 shows an overview of the proposed integrated CAE framework and the sequential inheritance of physical states from manufacturing processes to performance CAE.

The validity of the proposed framework was first evaluated using simplified structural components. Press forming CAE analyses were conducted under conditions reproducing actual manufacturing settings. Comparison with experimental measurements showed that deformation magnitudes were reproduced within approximately ±1 mm for most evaluation points, confirming that manufacturing-induced deformation was adequately represented.

For the welding process, press forming results were inherited as initial conditions, including geometry, thickness, plastic strain, and stress. Welding CAE analyses showed deformation trends consistent with experimental observations when manufacturing-induced physical states were inherited, whereas analyses without inheritance exhibited larger deviations. In the drying process, thermal stress CAE analyses were performed using the inherited welding results and reproduced furnace-atmosphere temperature history. The analyses revealed localized stress redistribution around spot welds caused by thermal expansion and contraction, even under low-temperature heating conditions. After validating the framework using simplified structures, performance CAE analyses focusing on axial crushing performance were conducted. When manufacturing-induced physical states were inherited, both the first and second peak crushing loads showed closer agreement with experimental results compared with analyses without inheritance.

The applicability of the framework to vehicle-level structures was further investigated using a side-impact CAE analysis with a simplified rigid barrier and a simplified vehicle body model focusing on the side outer components, based on an IIHS side impact test condition. Comparisons between CAE analyses with and without inheritance of manufacturing-induced physical states indicated differences in deformation amount, with smaller B-pillar deformation observed when manufacturing-induced physical states were considered.

Based on these results, it is concluded that the proposed integrated CAE framework enables the consistent transfer of manufacturing-induced physical states into performance CAE models and improves the reliability of performance prediction. Using analyses of simplified structural components, it was confirmed that manufacturing-induced physical changes were successfully reflected, and that discrepancies in axial crushing performance between CAE results and experimental test results were reduced, demonstrating the effectiveness of the proposed framework. Furthermore, application of the proposed framework to vehicle body structures indicated the possibility that manufacturing-induced physical states could influence deformation behavior in impact performance.

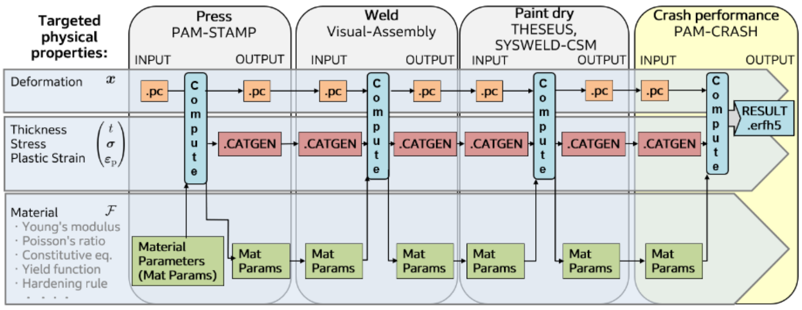

Fig.1 Integrated CAE Framework Overview