

Study on Crash Analysis Correlation of Aluminum Die Casting Components Using Simplified Casting Simulation

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In recent years, the application of aluminum die-cast components in vehicle structural parts has been expanding. Among the performance requirements for vehicle structural components, crash performance is particularly important, and accurate crash analysis is required to enhance development efficiency. Aluminum die-cast components exhibit spatial variations in material properties, and reflecting these variations in crash analysis is important for accurate simulation. Several methods have been reported, including measurement and incorporation of casting defects in prototype components, prediction of material property distributions from casting simulation results, and construction of regression models using machine learning based on casting simulation and measurement results. However, in the early development stage, component geometry and casting conditions, such as gate positions and runner layouts, have not yet been finalized, making methods that require prototypes or flow analysis challenging to apply. Although a simplified model that predicts solidification behavior using thermal analysis without flow analysis has also been reported, its application to material property mapping for crash analysis models has not been investigated. Therefore, this study investigated a method for predicting material property distributions and mapping them onto crash analysis models that can be applied in the early development stage.

The material properties required for crash analysis include yield stress (YS) and stress-strain curves for deformation behavior, as well as fracture models and fracture criteria for fracture behavior. Conventional casting analysis performs both flow and thermal analyses to predict temperature histories, solidification behavior, and casting defects related to molten metal flow. In contrast, the simplified casting analysis proposed in this study predicts solidification behavior using thermal analysis and calculates YS from the predicted solidification completion time. Solid elements of the target component were extracted from the crash analysis model, and the simplified casting analysis was performed using Ansys LS-DYNA, the same explicit solver used for crash analysis. This enables the existing crash analysis mesh to be utilized without a dedicated casting solver, simplifying mesh preparation and data conversion for material property mapping. A constant mold temperature and heat transfer coefficient were applied as boundary conditions on the component surface, while the initial molten metal temperature was assigned to all nodes. The temperature decreased after the start of the analysis, and solidification progressed when the temperature reached the solidification-start temperature. The time from the start of the analysis to completion of solidification was defined as the solidification completion time, t_s . Differences in t_s were observed between the component surface and interior. An empirical relationship between microstructural refinement and strength was used to calculate YS from t_s . The component elements were classified into regions according to their YS in 5 MPa intervals. The stress-strain curve was shifted to match the predicted YS, while the fracture criterion was adjusted so that the strain energy up to fracture remained constant.

The proposed method was evaluated using prototype die-cast components. For component A, tensile tests were conducted at 14 locations, and the measured YS values were compared with those predicted by the simplified casting analysis. The analysis was able to predict the trend in the YS distribution within the component. Next, a compression test of component B was reproduced using a conventional model (Uniform) and a mapped model (Mapped), as shown in Fig. 1. In the conventional model, material data obtained from tests of a prototype plate made of the same alloy were uniformly assigned throughout the component. Figure 2 compares the load histories of both models with the test result. The peak load error was reduced from +5.9% for the conventional model to +1.1% for the mapped model. When the YS of a specimen extracted from component B was used as a reference, the difference in YS was 25.2 MPa for the conventional model, whereas the difference between the mapped YS and the average YS was reduced to 6.7 MPa. These results suggest that YS can differ between a plate and a component of the same alloy due to differences in cooling conditions during casting. Furthermore, predicting the YS distribution before component prototyping using simplified casting analysis and applying the predicted material properties to the crash analysis model demonstrated improved crash analysis correlation.

In conclusion, the proposed method enabled the prediction of YS distributions based on solidification behavior using simplified casting analysis. Applying the predicted material properties to crash analysis demonstrated the potential to improve the representation of aluminum die-cast component properties and crash analysis correlation from the early development stage.

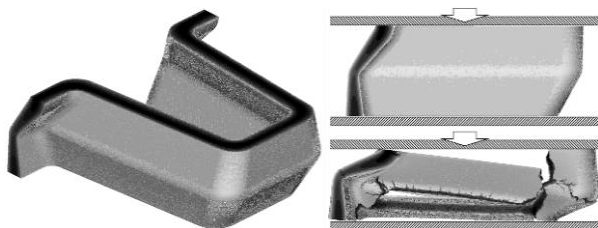


Fig.1 Compression Test and Simulation Model

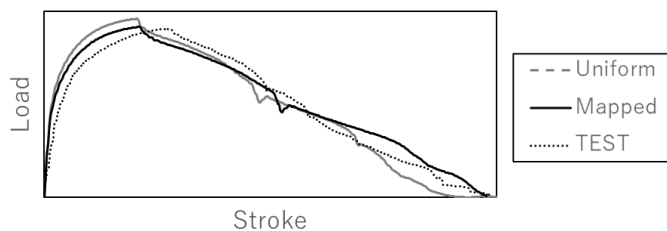


Fig.2 Comparison of Load-Stroke Curves